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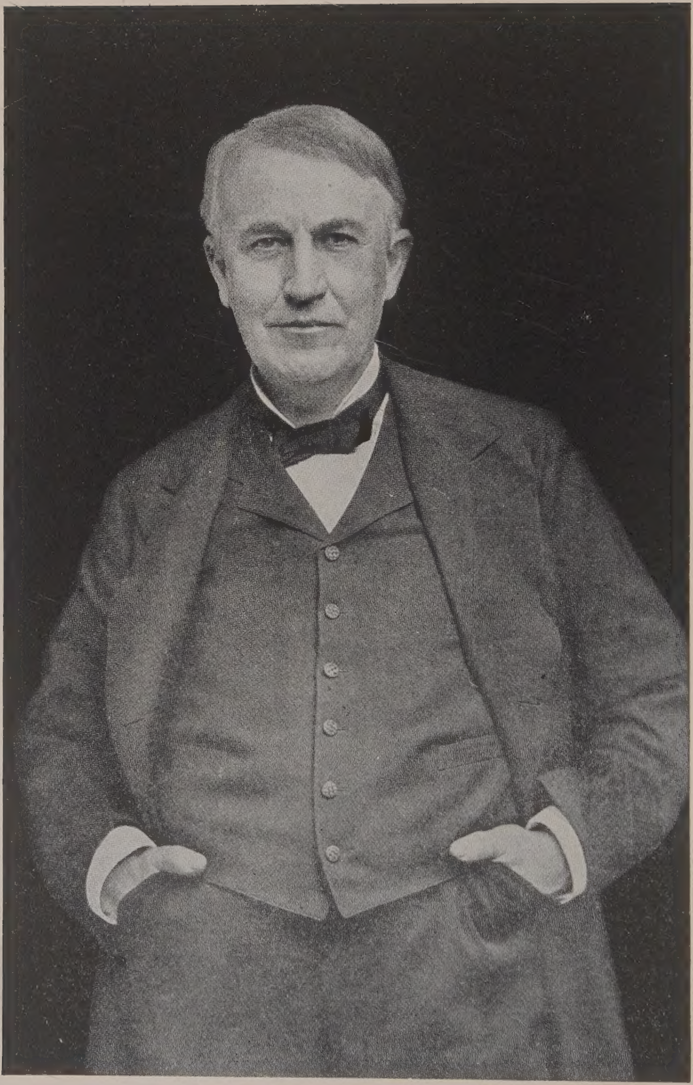

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Grateful acknowledgment is here made also for the invaluable co-operation of the foremost engineering firms, in making these volumes thoroughly representative of the best and latest practice in the design and construction of steam and electrical machines and machine tools; also for the valuable drawings and data, suggestions, criticisms, and other courtesies.

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¶ The instruction papers from which the Cyclopedia is compiled, have been prepared especially for home study by acknowledged authorities, and represent the most careful study of actual shop needs and conditions. Although primarily intended for correspondence study, many of the instruction papers of the School have been adopted as regular textbooks by the leading colleges and universities, among which may be mentioned Harvard University, Columbia University, Lehigh University, Iowa State College, University of Minnesota, Armour Institute of Technology, Pratt Institute, University of Michigan, University of Maine, the U. S. Government School of Submarine Defense; and for reference in practically all libraries.

¶ Years of experience in the shop, laboratory, and class-room have been required in the preparation of the various sections of the Cyclopedia. Each section has been tested by actual use, for its practical value to the man who desires to know the latest and best practice in the shop or engine room.

¶ Numerous examples for practice are inserted at intervals; these, with the test questions, help the reader to fix in mind the essential points, thus combining the advantages of a textbook and a reference work.

¶ Grateful acknowledgment is due to the corps of editors and authors, who have prepared the many sections of this work. The hearty co-operation of these men—engineers of wide practical experience and acknowledged ability—has alone made these volumes possible.

¶ The Cyclopedia has been compiled with the idea of making it a work thoroughly technical yet easily comprehended by the man who has but little time in which to acquaint himself with the fundamental branches of practical engineering. If, therefore, it should benefit any of the large number of workers who need, yet lack, technical training, the editors will feel that its mission has been accomplished.

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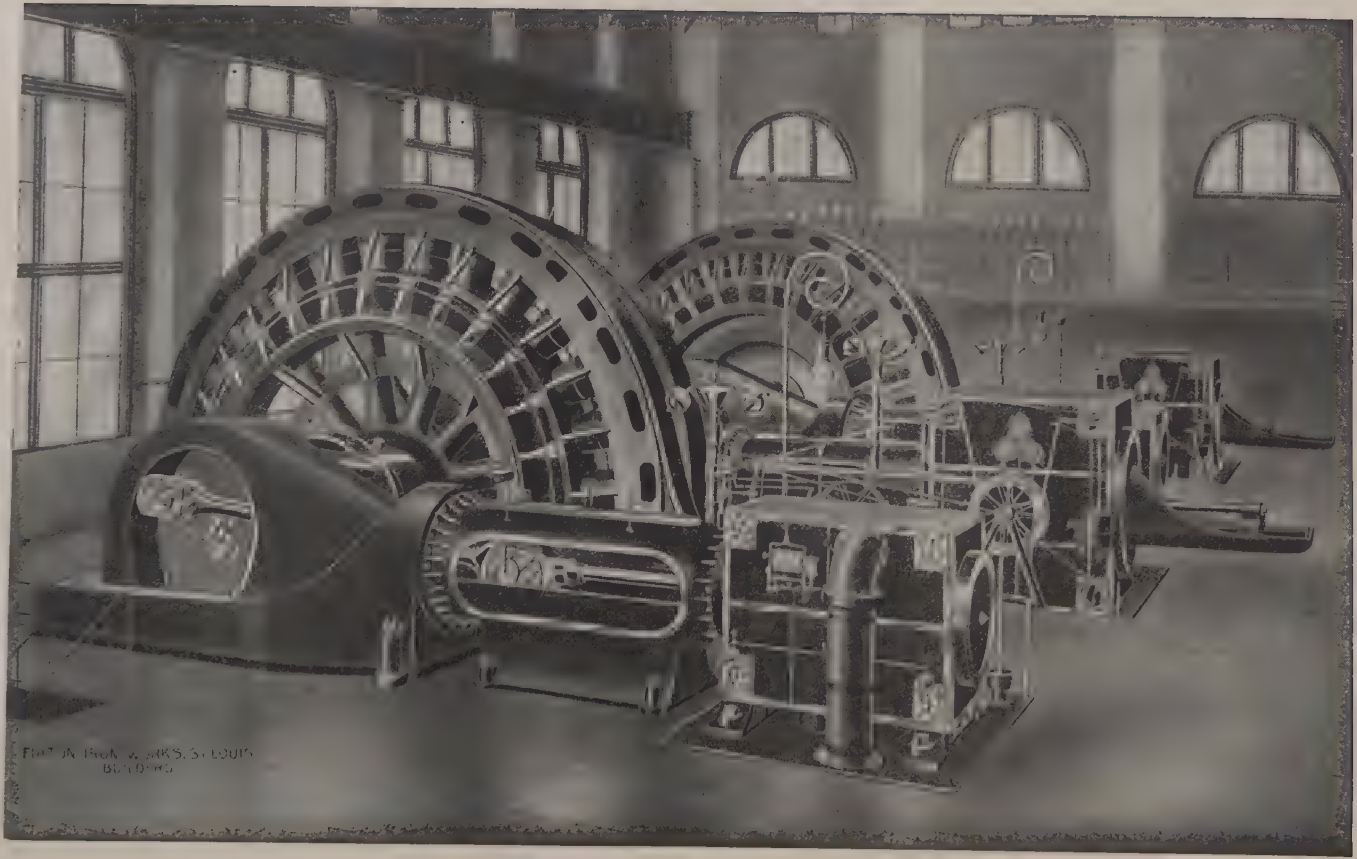

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DYNAMO-ELECTRIC MACHINERY

PART I

THEORY OF DYNAMO-ELECTRIC MACHINERY

A *dynamo-electric machine* is one which converts mechanical into electrical energy, or *vice versâ*, by means of the relative motion of a conductor carrying an electric current, and an interlinked magnetic field. When the conversion is from mechanical to electrical energy, the machine is called a *generator;* and when the conversion is from electrical to mechanical energy, the machine is called a *motor*. In order fully to understand the design and construction of these machines, it will first be necessary to consider the principles which govern their action.

Magnetic Field. It was early found that pieces of a certain kind of iron ore were capable of attracting bits of iron. From the name of the country in which this peculiar oxide of iron was first found, came the name of articles made of it—*i.e.*, *magnets*, from "Magnesia," in Asia. This oxide of iron is Fe_3O_4, commonly called *Magnetite*.

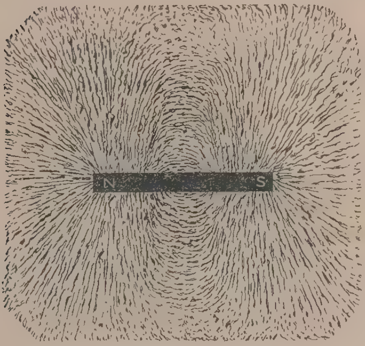

Fig. 1. Magnetic Field around a Bar Magnet.

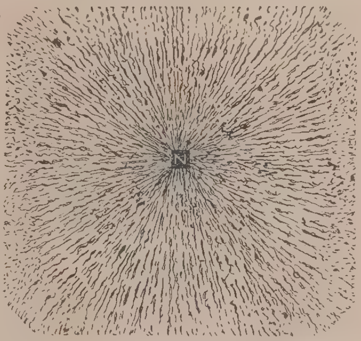

Fig. 2. Magnetic Field around One Pole of a Bar Magnet.

If one of these magnets shaped as a straight bar is held under a piece of cardboard upon which iron filings are sprinkled, it will be found that the filings settle down in curved lines forming a magnetic figure, the general form of which is shown in Fig. 1. When one of the poles of the magnet is held toward the cardboard, the filings will arrange themselves as shown in Fig. 2. These experiments show that the medium surrounding a magnet is in a state of stress, the space so affected being called a *magnetic field.* The influence of a magnet is supposed to extend in all directions indefinitely; *but as the force due to the magnet varies inversely as the square of the distance from it,* the effect is rendered practically negligible beyond a comparatively limited area.

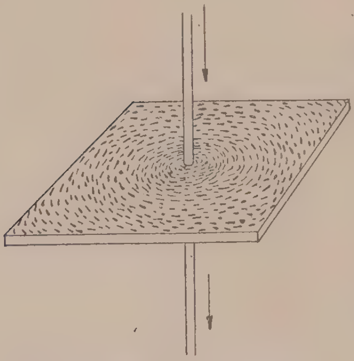

Fig. 3. Magnetic Field around a Current-Carrying Conductor.

When a conductor carrying a current of electricity is passed through a piece of cardboard with iron filings sprinkled on the board as before, we see (Fig. 3) that the filings arrange themselves in curved lines similar to those of Fig. 2; while, if the return circuit of the conductor be also poked through the card, the filings assume the alignment shown in Fig. 4. From the similarity of the phenomena, it may be concluded that a conductor carrying an electric current is surrounded by a magnetic field whose strength is a direct function of the current. This was first noted by Oersted, who in 1820 observed that a compass needle was deflected when placed near a conductor carrying a current of electricity, the direction of motion of the needle depending upon the direction of flow of the current.

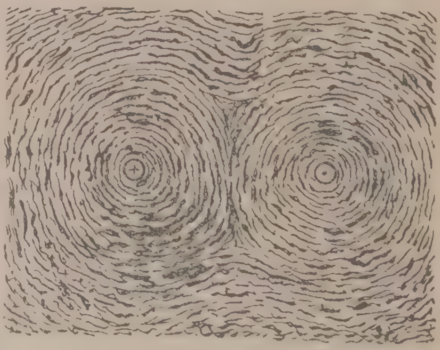

Fig. 4. Magnetic Field around Conductor and Return Circuit.

Lines of Magnetic Force. The magnetic figures in the previous paragraph indicate that the stresses in the medium surrounding a magnet or current-carrying conductor follow certain definite lines, the lines showing the direction of stress at any point. These are called *lines of magnetic force.* If, in addition, there be drawn as many lines per square centimeter cross-section of the field as there would be dynes of force acting upon a unit magnetic pole* placed at that point, then the total number of lines of magnetic force represents the *magnetic flux* through that cross-section; and the lines per square centimeter, the *flux-density.*

Solenoids. Now, suppose that a wire is bent in the form of a circular loop as in Fig. 5, and furthermore suppose that a current is traversing the conductor in the direction indicated. Then, according to a rule suggested by Maxwell,

> "The direction of the current and that of the resulting magnetic force are related to one another, as the rotation and travel of an ordinary (*i. e.*, right-handed) screw."

Consequently the lines of magnetic force would surround the loop in the manner shown. The field of such a loop, on being explored with a compass needle or filings, will be seen to retain the general character of the field surrounding a straight conductor; and consequently all the lines will leave by one face and return by the other, the entire number passing through the loop. Hence one face of the loop will be equivalent to the north pole of a magnet, and the opposite face will correspond to the south pole. In fact the loop will act exactly as if it were a thin disc magnetized perpendicularly to its plane.

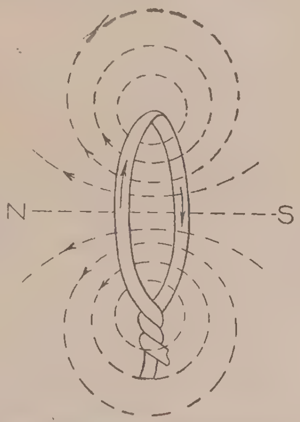

Fig. 5. Magnetic Field around a Conducting Loop.

By placing side by side several of these current loops, with their transverse axes in the same straight line, there is formed a *solenoid* (Fig. 6); and exploration of the resulting field by any of the above methods shows that the lines of force pass right through the interior of the solenoid, leaving by one end and returning by the opposite end as suggested by Maxwell's rule. A cylinder of soft iron inserted in the space within the solenoid will be found to act strongly as a magnet when the current flows around the solenoid; but if the current is interrupted, the magnetic effect almost disappears. Reversal of the current will be found to reverse the polarity of the core, while increasing the current augments the magnetic strength of the coil.

---

* A *unit magnetic pole* is one which, when placed at a distance of one centimeter from a similar pole, in vacuum or practically air, exerts upon it a force of one dyne.

Toroid. Bend the solenoid of the previous paragraph around until its ends meet; or produce the same winding by turning insulated wire around an endless ring core of circular cross-section. The arrangement thus produced will be a *toroid*, commonly called *Faraday's ring;* and if the wires are wound closely and uniformly over the whole periphery, the lines of force will be closed curves whose paths lie entirely within the turns; consequently there are no external poles—a unique electromagnetic condition.

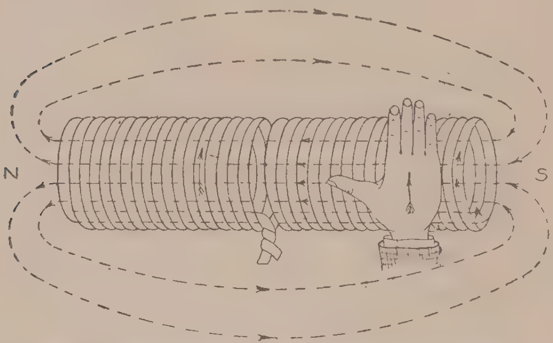

Fig. 6. Arrangement of Conductive Loops Forming a Solenoid, with Surrounding Magnetic Field.

Magneto-Electric Induction. Thus far the condition of the magnetic field has been determined by means of filings or magnets; but neither of these methods can be used to explore the interior of an iron-cored toroid. It is possible, however, to employ for this purpose the principles of *magneto-electric induction* discovered by Faraday in 1831. One of the laws governing this phenomenon, first enunciated by Neumann in such manner as to permit determination of the electromotive force developed, is as follows:

> "Whenever the flux interlinked with a circuit is varying, there is an e. m. f. acting around the circuit, proportional to the time rate of change of the flux, the positive direction of the e. m. f. and the positive direction of the flux passing through the circuit being related to each other as are the rotation and travel of a right-handed screw. That is, if a circular loop is moved in the field of a magnet in such a way that it does not enclose the same amount of flux at any two successive instants, then there is induced in the loop an e. m. f. whose value is proportional to the change of enclosed flux per unit time. A similar effect will be obtained by keeping the loop fixed, and moving the magnet."

We thus have a way to investigate the condition of the field within the solid-cored toroid previously mentioned. Suppose a loop of insulated wire to be placed around the toroid in Fig. 7, and suppose the terminals of this loop to be led to a ballistic galvanometer (that is, an instrument which will measure current impulses). Then if the magnetizing coil of the toroid be energized by passing a current through it, the galvanometer will give a sudden throw the instant the current is started. Similarly, when the circuit is broken and the current ceases, the galvanometer indicates the passage of another current impulse through the loop, the deflection, however, being in the opposite direction.

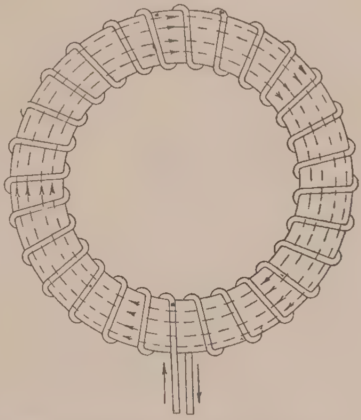
Fig. 7. Lines of Force in Toroid Surrounded by a Magnetizing Coil.

The loop is next removed from the toroid and placed in front of an iron-cored solenoid which can be energized or de-energized at will by closing or opening a switch, and it will be found that similar effects are produced. Let, now, the electromagnet be energized and de-energized periodically, and the loop or exploring coil be turned so that its axis occupies every possible direction in space, the center of the loop remaining stationary throughout. It will be found that when this axis is in one particular plane, no impulse will pass through the exploring coil when the exciting current of the electromagnet is caused to flow, to cease, or to reverse. From what has been explained previously, we see that in this case the loop interlinks with no flux, hence its plane must be parallel to the direction of the flux. Also we see that when the plane of the loop takes any other position, the flux interlinked with it depends upon the relation between the plane of the loop and the direction of the flux. If we call the angle between the direction of the flux and the axis of the loop α, the flux enclosed by the loop for any given value of the exciting current of the electromagnet will be proportional to the cosine of α. The quantity we are thus investigating is a directed quantity, and may therefore be represented by a vector.

Lines of Magnetic Induction. This quantity is called the *magnetic induction* or *flux,* and its direction at any point is defined as that of the axis of the loop when in the position giving the greatest inductive effect on energizing or de-energizing the electromagnet. Its direction is also defined by Neumann's law. If, now, a curve be drawn following the direction of the flux, this curve will be a line of magnetic induction. The flux and flux-density are defined in a way precisely similar to magnetic force.

Relation between Magnetic Force and Magnetic Induction. In the earliest of Faraday's experiments with solenoids, he found that the flux through any of these was much greater when iron was inserted than when air or wood was enclosed by the coil of wire. He ascribed this peculiar circumstance to the greater "conducting power of the magnetic medium for lines of force." Lord Kelvin introduced the phrase *magnetic permeability* for this property of magnetic materials, and it is defined as the ratio between the magnetic induction (B) produced in the medium and the magnetic force (H) to which that induction is due; *i. e.,*

$$\mu = \frac{B}{H}.$$

Magnetic Permeability. The precise notion now attached to this term is that of a numerical coefficient, and it is analogous to electrical conductivity. Its value is dependent upon the character of the substance and the magnetizing force or m. m. f. applied to the substance. For vacuum its value is unity; for air it is practically unity; for magnetic materials it is greater than 1 and may reach 2,500 for soft iron; while for diamagnetic materials it is slightly less than 1. The permeability of such non-magnetic materials as silk, cotton, and other insulators, also of brass, copper, and other non-magnetic metals, is taken as unity, being practically the same as for air.

The permeability of iron, however, varies very greatly with the degree to which it has been magnetized. In all kinds of iron (after passing the initial stage mentioned below), the magnetizability of the material becomes diminished as the actual magnetization is pushed further; in fact, there is a tendency to magnetic saturation. In other words, when the piece of iron has been magnetized up to a certain degree, it becomes less permeable to further magnetization; and although actual saturation is never reached, there is a limit beyond which the magnetization cannot be increased with practical advantage. This is shown in Fig. 8, which represents the permeability curve of a sample of good iron or steel as used in dynamo magnet construction. The practical limit of the flux-density (B) in good wrought iron and in mild steel, is about 20,000 lines of magnetic induction per square centimeter; and in cast iron the saturation limit in practice is about 12,000 lines per square centimeter. In square-inch units these limits are, for wrought iron and mild steel, about 125,000 or 130,000 lines per square inch; and for cast iron, about 70,000 lines per square inch.

Magnetic Circuit. Returning to the toroid of Fig. 7, we see that the lines pass through the interior of the toroid, forming a closed magnetic circuit. Now, it is found that the total flux within the toroid is equal to the ratio between the magnetomotive force acting around the magnetic circuit and the reluctance of that circuit; that is

$$\phi = \frac{\text{m. m. f.}}{R},$$

in which,

ϕ = Total flux;

m. m. f. = Magnetomotive force;

R = Magnetic reluctance.

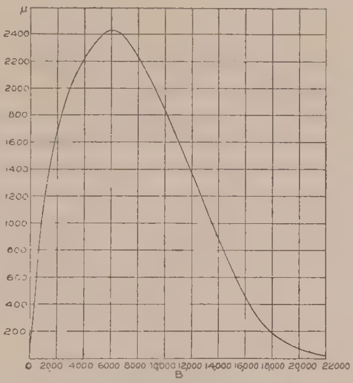

Fig. 8. Permeability Curve of Iron or Steel Used in Dynamo Magnet Construction.

Magnetomotive Force. By this term is meant the total magnetizing power of an electric current circulating in a coil. It is found, when a current flows in a wire wound several times around a core, as in Fig. 9, that the magnetizing power is proportional both to the strength of the current and to the number of turns of wire. The magnetizing power is independent of the size of the wire or the coils and of their shape, remaining also the same whether the spirals are close together or wide apart. Hence if T be the number of turns in the coil, and I be the current in amperes passing through each turn, the magnetomotive force is,

$$\text{m. m. f.} = \frac{4}{10}\,\pi \times I\,T = 1.257\,IT.$$

A straight conductor carrying an electric current of which the return is very distant, as in Fig. 10, is surrounded by circular concentric lines. Taking one of these lines at a distance r centimeters from the axis of the wire, which we suppose to be carrying I amperes (that is, $\frac{I}{10}$ units of current in C. G. S. electromagnetic units), the intensity of the field at any point at radius r has the uniform value $\frac{2I}{10r}$, and its direction is that of the given line, of which the length is $2\pi r$. Hence the total force around the circle of radius r concentric with the axis of the conductor, will be the product of the force at any point of its circumference into the length of this circumference; *i. e.*,

$$\frac{2I}{10r} \times 2\pi r = \frac{4\pi}{10} I.$$

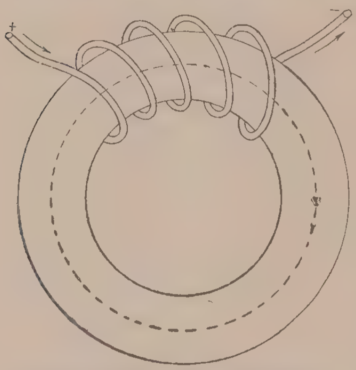

Fig. 9. Showing Relation between Magnetizing Power of a Coil and Its Number of Turns.

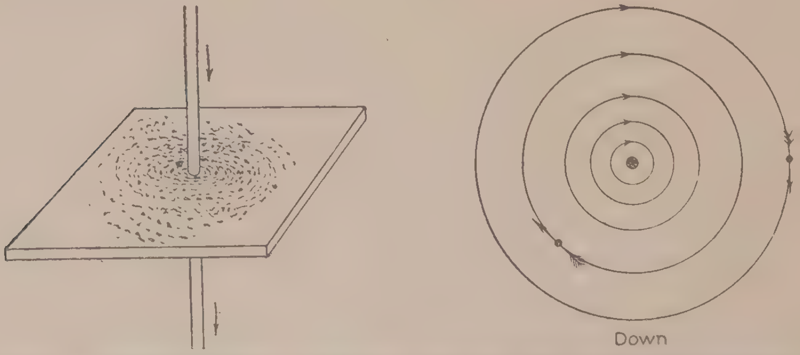

Fig. 10. Illustrating Variation in Intensity of Magnetic Field Surrounding a Conductor with Distant Return.

And if the single wire be replaced by T turns, the force will be T times as large, or $\frac{4\pi}{10} I\,T$, $I\,T$ being called the *ampere-turns.*

Reluctance. We have seen from the equation of the magnetic circuit, that the total flux is inversely proportional to the reluctivity of the materials of which it is composed; it is directly proportional to the permeability which is the reciprocal of the reluctivity. The reluctance or magnetic resistance of a circuit is therefore obviously proportional to its length, and inversely proportional to its area of cross-section and its permeability; that is,

$$R = \frac{l}{\mu A}$$

In designing electromagnets, before calculations can be made as to the size of the iron core required, it is necessary to know the magnetic properties of that particular iron; for it is obvious that inferior permeability demands a larger cross-section to obtain a given flux, or inferior permeability will require more turns of copper wire to be used.

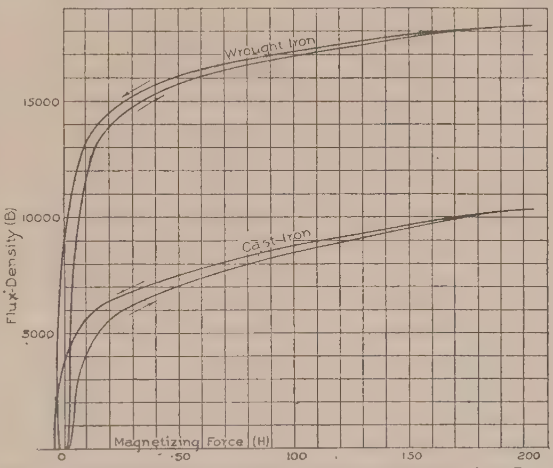

Fig. 11. Magnetization Curves of Wrought Iron and Cast Iron.

Magnetization Curves. A convenient method of studying the magnetic facts respecting any particular brand of iron, is to plot as a diagram the *curve of magnetization*—that is, the curve representing the relation between the magnetic force plotted horizontally, and the magnetic induction plotted vertically.

The upper curve in Fig. 11 gives the behavior of annealed wrought iron. The ascending curve shows the relation between the intensity of the magnetizing force H and the flux-density B during the process of increasing the magnetizing force from zero to about 210 units; and the descending line shows the same relation during the process of decreasing the magnetizing force to zero, and then reversing it so as to remove the residual magnetic lines. The lower curve shows the behavior of grey cast iron.

Every sample of iron will show a similar set of results, which can be plotted in the form of a curve that is characteristic. The curves for cast iron and hard steel always have lower values than those for wrought iron or mild steel. In addition, it will usually be noted that when a fresh piece of iron or steel is subjected to a gradually increasing magnetizing force, the lowest part of the curve presents near its origin a small concavity (see Fig. 11), showing that under certain magnetizing forces the permeability is greater than at the initial stage. This concavity is more pronounced in the case of hard iron and steel than in the case of soft iron, but the curves differ in detail even in different specimens of the same sort of iron.

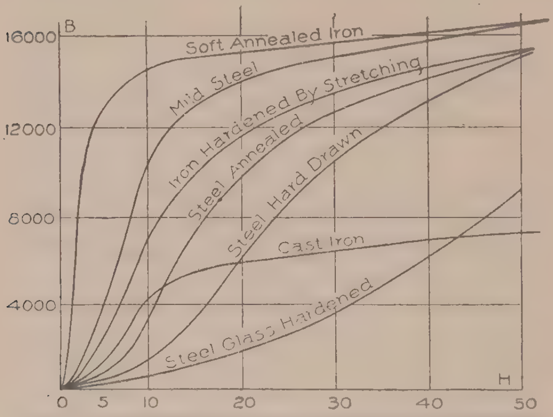

Fig. 12. Magnetization Curves of Various Irons and Steels Used in Dynamo Construction.

Fig. 12 gives a comparative idea of the relation between the magnetic properties of the various irons and steels used in dynamo manufacture.

Effect of Air-Gap in Magnetic Circuit. Thus far we have considered the magnetic circuit as made up of a solid, endless ring of iron. But suppose it to be built up partly of iron and partly of some non-magnetic material, as air or copper. We then have, as the total reluctance of the magnetic circuit, the sum of the reluctances of the various parts of the circuit. For example, if we have a ring made up of l_i centimeters of iron and l_a centimeters of air, the reluctance of this magnetic circuit would be,

$$R = \frac{l_i}{\mu_i A_i} + \frac{l_a}{\mu_a A_a}.$$

in which μ and A are respectively the permeability and cross-sectional area of the materials denoted by the subscripts.

It follows, then, that the total flux of such a circuit would be,

$$\phi = \frac{0.4 \pi I T}{\frac{l_i}{\mu_i A_i} + \frac{l_a}{\mu_a A_a}},$$

in which $I T$ represents the ampere-turns and $.4 \pi = 1.257$ as before.

Since the magnetic permeability of air is constant and practically equal to unity, we see that an air-gap or its equivalent introduced into a magnetic circuit previously consisting of iron, will increase the m. m. f. required to produce the same flux as before, due to the inferior permeability of the non-magnetic portion.

S. P. Thompson makes this plain by a graphical method as follows:

"The curve OcC (Fig. 13) represents the relation between the number of magnetic lines in an iron bar and the ampere-turns ($= Hl \div 1.257$) needed to force these magnetic lines through the iron. For example, to reach the height c, the excitation has to be of the value represented by the length Ox_1. On the same diagram the line ObB represents the relation between the magnetic flux across the air-gap and the ampere-turns of current (stream) required to force this flux across. If the gap were 1 centimeter long, 0.795 ampere-turn would produce the field $H = B = 1$. In the present case the gap is supposed to be shorter than 1 centimeter, the line sloping up at such an angle that the length Ox_2 represents the ampere-turns requisite to bring the magnetic flux up to b, the same height on the scale as c. The total amount of excitation required to force these magnetic lines through air and iron will (neglecting leakage) be the sum of the separate amounts. The point x_3 is chosen so that Ox_3 is equal to the sum of Ox_1 and Ox_2, or that the distance of the point r from the vertical axis is equal to the sum of the respective distances of c and b. If the same thing is done for a large number of corresponding points, the resultant curve OrR may be constructed from the two separate curves. It will be seen, then, that in general the presence of a gap in the magnetic circuit has the effect of causing the magnetic curve to rake over, *the initial slope being determined by the air-gap.*"

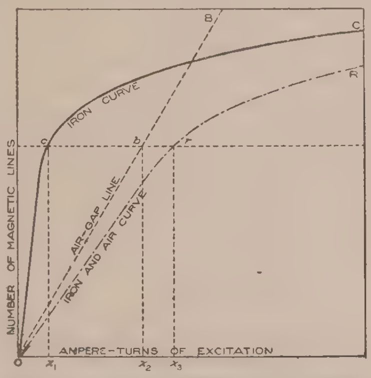

Fig. 13. Graphical Method of Showing Effect of Air-Gap in a Magnetic Circuit.

Effect of Joints in the Magnetic Circuit. Ewing* tried the effect of different numbers of joints in the iron of a magnetic circuit for various magnetizing forces, his results being given in Fig. 14. They refer to a bar of wrought iron cut across, first into two pieces, then into four, and finally into eight pieces. He also found that when the faces of a cut were carefully surfaced up to true planes, the disadvantageous effects of the cut were considerably reduced, and under considerable pressure applied externally almost vanished. An ordinary joint is equivalent to an air-gap of about .005 cm. = .002 inch.

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* "Magnetic Induction in Iron and Other Metals," London, 1892, pages 208 to 273.

Effects of Heat. When iron is raised to 600°C., it begins to lose its magnetic properties; and, if the temperature is increased to 780°C., they entirely disappear. At temperatures between 0°C. and 100°C., various other effects have been noted, such as *aging*—that is, an increase in the hysteresis. In dynamos, however, these effects are practically negligible, since the working temperature should not exceed 75°C.

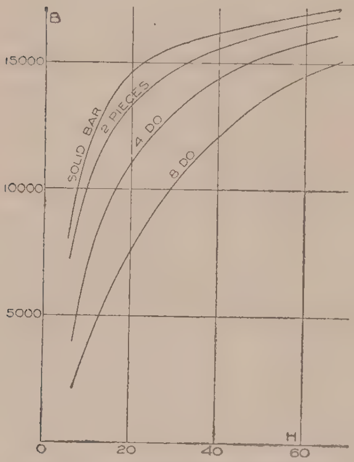


Fig. 14. Curves Showing Effects of Joints in Magnetic Circuit.

Residual Magnetism. It has been found, when the magnetizing forces have been removed from a specimen of iron, that it still exhibits some phenomena of magnetism. This residual magnetism depends for its magnitude upon the character of the iron or steel, being greater in the harder grades than in the softer ones.

Referring to Fig. 11, it will be seen that when a specimen of wrought iron was magnetized to a high flux-density, and the m. m. f. then reduced to zero, the flux-density diminished only to about 7,300 lines per square centimeter, the descending curve of magnetization being above the ascending one. The name *remanence* is given to the lines per square centimeter so remaining. Furthermore, in order to remove this remanence, it is necessary to apply a certain negative magnetizing force, termed by Hopkinson the *coercive force*. It varies in magnitude from 2 for soft wrought iron, to about 80 units or more for hard steel.

Effects of Cycles of Magnetization. This tendency of the magnetic effects to lag behind the forces producing them has been named by Ewing *hysteresis*, and is best studied by subjecting the iron specimen to one or more complete cycles of magnetization. For instance, suppose the m. m. f. applied to a piece of iron to be increased gradually from zero to a maximum value, then decreased through zero to an equal negative maximum, and finally to reverse and return through zero to the positive maximum value. The magnetic changes for such a complete cycle are shown in Fig. 15 for specimens of iron and steel respectively.

The process as shown by the diagram, is started with the flux-density and m. m. f. at zero. The latter is then increased to about 60 units, in the case of the piece of iron, the resulting flux-density being 16,000. The m. m. f. is then reduced to zero, the flux-density only decreasing to 12,800. At a m. m. f. of –3, the flux-density is brought to zero; that is, –3 is the coercive force, and 12,800 the remanence. With a m. m. f. of – 60, the flux-density is – 15,500; and varying the m. m. f. from this point to zero, leaves the specimen with a flux-density of – 12,000. Further increasing the m. m. f. until the flux-density becomes zero, the final m. m. f. is found to be + 3. From this point the m. m. f. is increased to its former maximum value, this ascending curve differing a little from the first. Thus we see that when a specimen of magnetic material is put through a complete magnetic cycle, the coincident values of the m. m. f. and the flux-density form a close curve. The area thus enclosed has been shown by Warburg and Ewing to represent the energy wasted as

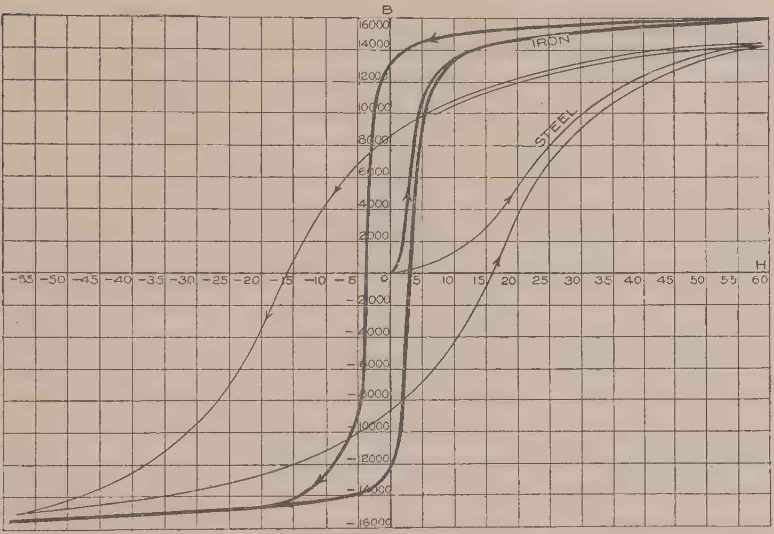


Fig. 15. Curves Showing Magnetic Changes in Iron and Steel Due to Complete Cycles of Magnetization.

TABLE I

Hysteretic Constants for Different Materials

Material	Hysteretic Constant η	Material	Hysteretic Constant η
Very soft iron wire.	.002	Soft annealed cast steel. . .	.008
Very thin soft sheet iron. . .	.0024	Soft machine steel.	.0094
Thin good sheet iron.	.003	Cast steel.	.012
Thick sheet iron.	.0033	Cast iron.	.016
Most ordinary sheet iron. . .	.004	Hardened cast steel.	.025
Transformer cores.	.0045		

heat in the material, when the specimen is put through a complete cycle; and its value depends upon both the character of the material, and the degree of magnetization, being greater for hard steel than for soft iron with the same range of magnetization.

Iron, when placed in an alternating magnetic field, is not only subjected to the hysteresis phenomena above considered, but it also becomes subjected to a set of parasitic electrical currents. These tend further to heat the iron, and are called *Foucault* or *eddy currents;* their path, by Maxwell's law, is perpendicular to the direction of the flux. Their value may be lessened by increasing the resistance of their path—that is, by *laminating the iron in a direction parallel to the direction of the flux and perpendicular to the path of these currents,* each sheet of iron being insulated from its neighbors. In practice, these laminæ vary from about 15 to 25 mils (0.015 inch to 0.025 inch) in thickness.

Calculation of Heat Waste in Iron Cores. From consideration of a great many tests of hysteretic losses, Dr. C. P. Steinmetz proposed the following law connecting the hysteresis loss h in ergs per cubic centimeter per cycle and the maximum flux-density B attained during a cycle:

$$h = \eta B^{1.6},$$

wherein η is a coefficient called the *hysteretic constant,* depending for its value upon the quality of the material. Some of these constants are given in Table I for ordinary frequencies. This law is practically true for all cycles ranging up to 200 per second.

By applying the proper transformation factors, the Steinmetz formula reduces to:

$$W_h = 0.83 \times \eta \times f \times B^{1.6} \times 10^{-7},$$

wherein

W^h = Hysteresis loss in watts per cubic inch of iron;
f = Frequency in cycles per second;
B = Flux-density in lines per square inch.

In Fig. 16 are given graphically the hysteresis losses in watts per cubic inch of iron per cycle per second, with various hysteretic constants.

Besides the hysteretic loss in iron cores, there is also the eddy-current loss, which varies directly as the square of the thickness of the iron laminæ, as the square of the maximum flux-density, and as the square of the frequency. The formula obtained by calculation and found to agree closely with practice, is:

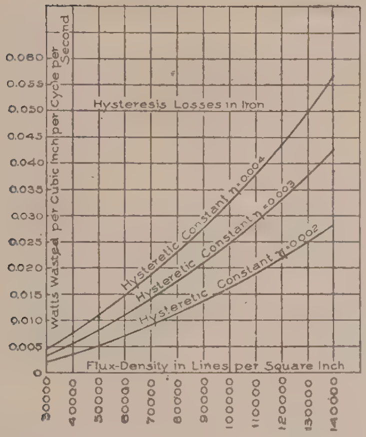


Fig. 16. Curves Showing Hysteresis Losses in Iron with Various Hysteretic Constants.

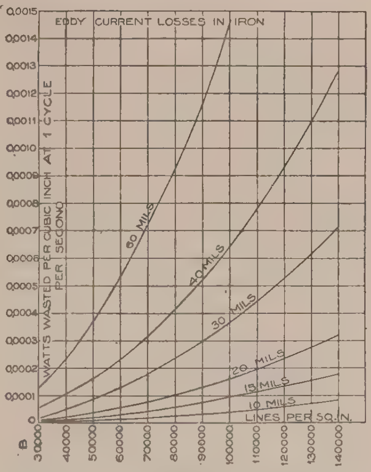


Fig. 17. Curves Showing Eddy-Current Losses in Iron of Varying Thickness under Varying Flux-Density.

$$W_e = 40.6 \times t^2 \times B^2 \times n^2 \times 10^{-12},$$

wherein

W_e = Watts loss due to eddy currents per cubic inch of iron;
t = Thickness of the iron plates, in inches; and the other symbols have the meanings previously assigned.

Fig. 17 exhibits values of W_e graphically for various thicknesses of iron over wide ranges of flux-density at one cycle per second.

The sum of these losses for any electrical machine is called for brevity the *iron-losses* of that machine. Calculations for actual machines will be given later.

Rotational Hysteresis. When a piece of iron is rotated in a magnetic field, it passes through a magnetic cycle, but in a way far different from that which has been described. Mordey found the losses to be slightly lower for rotation than for reversal; while Baily went further and showed (Fig. 18) that the former loss was slightly greater than the latter for flux-densities up to 15,000 lines per square centimeter, but that beyond this point the loss due to rotation rapidly diminished with increase in flux-density.

Owing, however, to eddy-current losses, the flux-densities in those parts of electrical machines which rotate in a fixed magnetic field are not allowed to exceed 15,000 lines per square centimeter (15,000 × 6.45 lines per sq. in.), except in the armature teeth of direct-current machines. We may therefore neglect this difference, as is usual in practice, and may calculate both kinds of hysteresis loss by the formula previously given. According to Ewing, this rotation loss is *molecular magnetic friction* and not true hysteresis, because the magnetization does not necessarily lag behind the m. m. f.

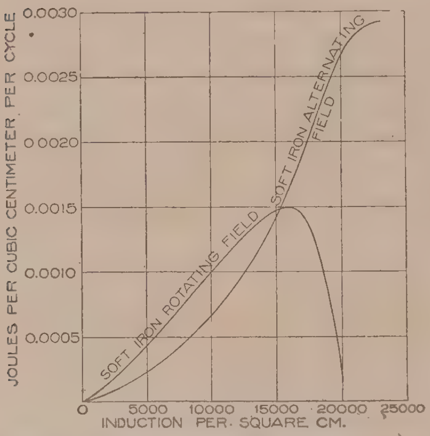
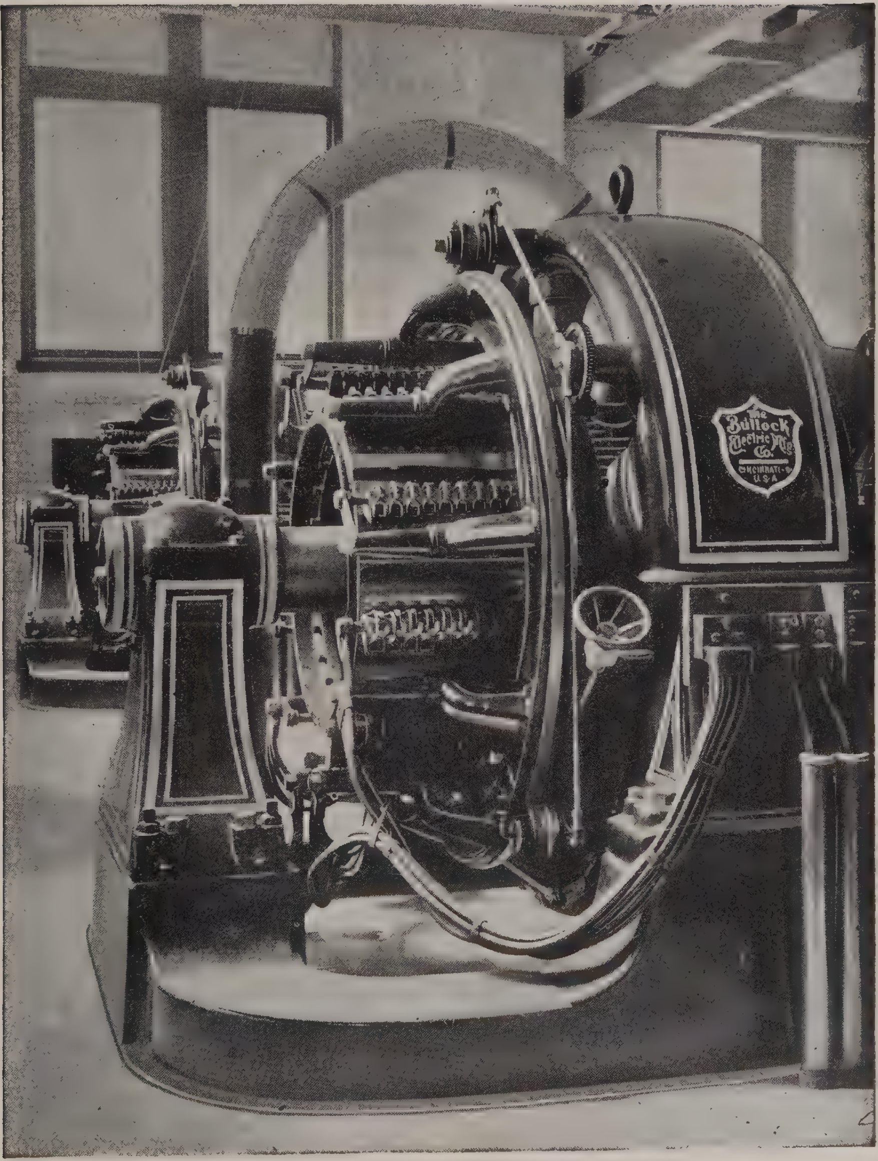


Fig. 18. Curves Showing Relation between Hysteresis Losses in Rotating and Alternating Fields.

Miscellaneous Magnetic Effects. *Retardation of Magnetization.* It has long been known that, owing to the eddy currents produced in the iron cores of electromagnets, the magnetism of the inner part builds up less rapidly than that of the outer parts. Similarly, when the m. m. f. is cut off, the inner part of the core retains its magnetism longer than the outer parts. In dynamos with large field-magnets, several minutes may elapse before the field will build up or change, and Hopkinson has shown that the retardation varies as the square of the linear dimensions of the core.

Magnetic Creeping. Ewing found that when a steady m. m. f. was applied to a specimen of iron, and the magnetism measured at intervals, the flux-density kept continually creeping up although



250 K.W. ENGINE-TYPE GENERATOR
at Prudential Life Building, Newark, N. J.
Bullock Electric Manufacturing Co.

the m. m. f. was absolutely constant. He named this *viscous hysteresis;* but it is a true magnetic lag, and must not be confounded with the lag in phase resulting in the formation of a loop, or the lag due to self-induction occasioned by eddy currents in the iron.

Slow Changes in the Magnetic Properties of Iron. When iron is continually subjected to rapidly alternating flux-densities, especially when the temperature rises above 100°C., it is found that the hysteretic loss is perceptibly increased. This effect has been observed in connection with transformers, where the iron losses play an important part in the working; but in continuous-current dynamos and motors the effect is negligible. (See page 12).

Magnetic Dampers. If a magnetic flux, whether in air or iron, be surrounded by a closed electrical circuit, any change in the value of the flux will induce an e. m. f. in that metallic circuit, tending to oppose the flux change. It has suggested itself, therefore, to builders of dynamos, to surround the magnet-poles with copper bands in order to reduce the possibility of sudden field fluctuation. This feature is employed extensively in alternating-current generators, synchronous motors, and rotary converters, under the name of *dampers* or *damping rings.*

Generation of E. M. F. by Cutting Flux. Whenever lines of magnetic flux are cut by a conductor, an e. m. f. is produced in that conductor, the value of the e. m. f. being one volt when 100,000,000 or 10^8 lines are cut per second. In other words, the e. m. f. depends solely upon the *time rate* of cutting, so that one volt would also be set up if 10^6 lines were cut in one-hundredth of a second. In both cases the time rate of cutting is supposed to be uniform throughout the given time.

The generation of e. m. f. is absolutely certain, no matter when or by what process the lines are cut. A *current,* however, will flow only when there is a closed electrical circuit. A straight bar of copper, for example, cutting across a magnetic field, would have a potential difference established between its ends; but, excepting a slight displacement current at the start, no current would flow until the electrical circuit was completed. We should distinguish, therefore, between the generation of an e. m. f. and the flow of a current. Thus, it may happen that two or more opposing voltages neutralize each other, so that no current whatsoever flows, even though the electrical circuit is complete. This is the case when a copper ring is moved in its own plane across a uniform field; the two halves cut an equal number of lines, and the e. m. f. produced in one half is exactly equal but opposite to that produced in the other half of the ring, making the current-flow zero. This explains the fact that the flux in a coil of wire must be varied in order to permit a current to flow; or, in other words, the coil must be filled with and emptied of, lines of magnetic induction, in which case an alternating current is produced. This is often stated so broadly, however, that it seems to mean that an e. m. f. cannot be obtained in a uniform field. As already stated, an e. m. f. *must* be produced whenever magnetic lines are cut, though a flow of current may not result.

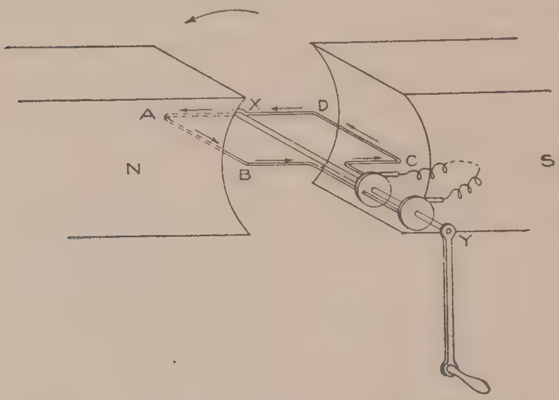


Fig. 19. Illustrating the Elementary Principles of the Generator.

Elementary Generator. The simplest form of generator consists of a loop of wire arranged to rotate in a uniform magnetic field, Fig. 19. The generation of e. m. f. in such a dynamo will be as follows: Assume the loop with its plane parallel to the direction of the flux. If, then, the loop be rotated counter-clockwise about its axis XY, the sides AB and CD, which cut lines of magnetic induction, will have an e. m. f. induced in them that will tend to cause a current flow in the directions indicated by the arrows. The value of this e. m. f. will depend upon the speed or *time rate* of cutting; and since this rate is greatest when the plane of the loop is parallel to the direction of the flux, the e. m. f. developed at the instant represented in Fig. 19 will be a maximum. As the loop approaches the 90° or vertical position, the generated e. m. f. gradually decreases because the rate of cutting is diminishing, until, at the 90° position, the cutting of the flux and the generated e. m. f. are both zero. If the rotation is continued, the rate of cutting gradually increases until the 180°

position is reached, where it again becomes a maximum, so that the e. m. f. generated at this intant is also a maximum. The cutting, however, in the two quadrants following the 90° position, has been in the opposite direction to that occurring in the first quadrant, so that the direction of the e. m. f. generated in the second and third quadrant is reversed with respect to that generated in the first quadrant. In passing from the 180° position to the 270° position the rate of cutting and the generated e. m. f. again diminish to zero; and from 270° to the 360° or 0° position, the rate of cutting increases and the direction of the generated e. m. f. is the same as that produced in the first quadrant, the e. m. f. rising once more to a maximum value at the 360° position.

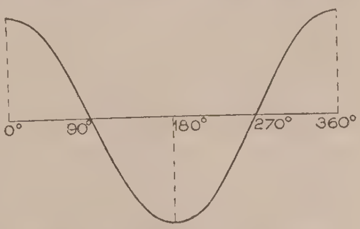


Fig. 20. E. M. F. Curve of Simple Generator Shown in Fig. 19.

Plotting the various instantaneous values of the e. m. f. so generated, we obtain the curve shown in Fig. 20. Such an e. m. f. is called an *alternating* one, because of its reversal from positive to negative values; that is, it tends to produce a current, first in one direction and then in the other direction, through the circuit. If, however, it is desired to supply the external circuit with a direct or continuous current, a special rectifying device called a *commutator* must be added.

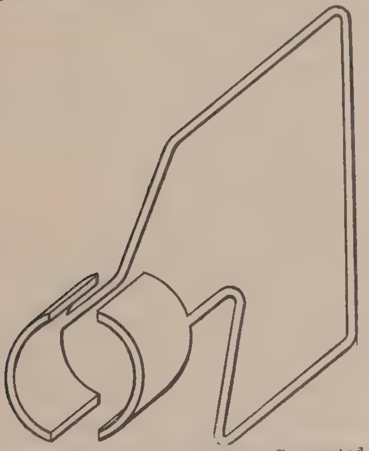


Fig. 21. Simple Commutator Connected to Loop with Single Turn.

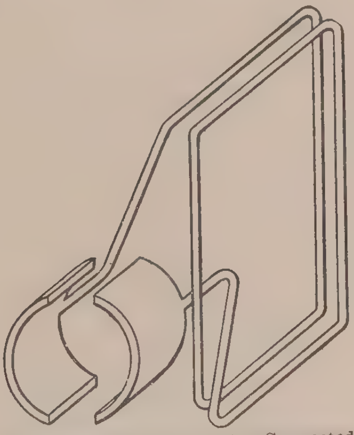


Fig. 22. Simple Commutator Connected to Loop with Double Turn.

In its simplest form, a commutator consists of a metallic tube slit longitudinally into two equal parts and mounted on a cylinder of insulating material, each half being connected to one terminal of a loop as indicated in Fig. 21. Fig. 22 shows a similar arrangement, except that the loop has two turns instead of one. Against this commutator, at diametrically opposite points, press a pair of metallic springs or brushes which lead the current due to the generated e. m. f. to the external circuit. If, as in Fig. 23, these brushes are so set that each half of the split tube moves out of contact with one brush and into contact with the other brush at the instant when the loop is passing through the positions where the time rate of cutting is minimum (as indicated in the enlarged end view of commutator shown at *A*), the alternating e. m. f. generated will produce in the external circuit a rectified, commutated, or unidirectional current. That is, the current in the external circuit will flow in one direction. If this external current be plotted, it will be of the pulsating character shown in Fig. 24. This explanation need not be changed, if, for a single loop, we substitute a coil wound on an iron ring as in Fig. 25. The effect of this is to increase the generated e. m. f. by increasing the number of times the electrical circuit cuts the flux. Now, referring again to Fig. 21, suppose, instead of one coil as there shown, we have two coils mounted side by side and

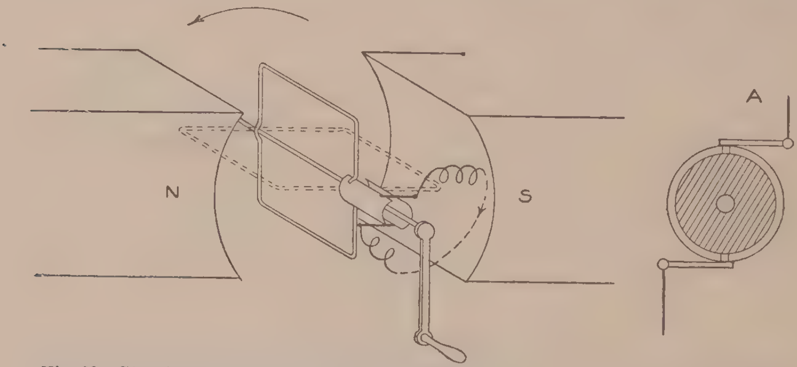


Fig. 23. Simple Form of Generator, Showing Arrangement of Brushes in Contact with Commutator to Give Unidirectional Current in External Circuit.

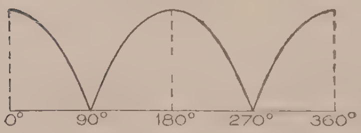


Fig. 24. Curve of Commutated Current.

connected in parallel to the commutator segments, we shall then obtain the elementary conditions shown in Fig. 26. If, then—similarly to the arrangement developed in Fig. 25—we place an exactly similar coil at the opposite side of the ring, as in Fig. 27, we see that when its terminals are connected to the same two half-rings as the first, the two coils are in parallel, and though the voltage generated by revolving this winding with two coils is no greater than with one coil, the current-carrying capacity of the resultant winding is evidently doubled.

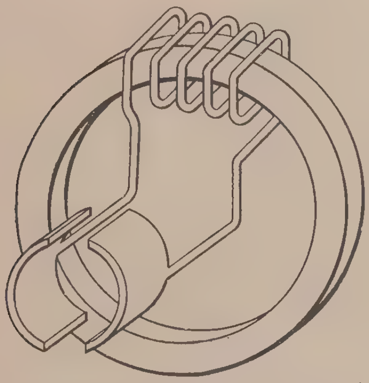


Fig. 25. Simple Ring Armature with One Coil.

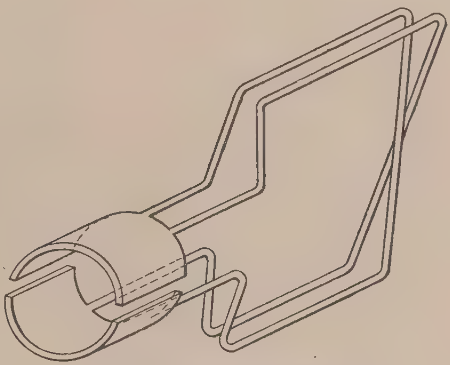


Fig. 26. Simple Loop Armature with Two Coils in Parallel.

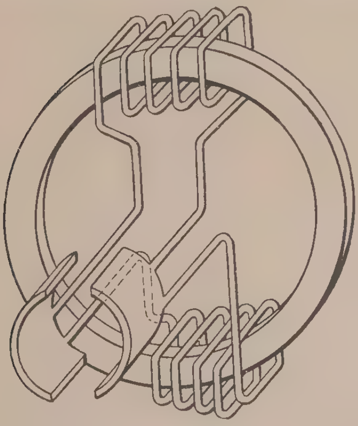


Fig. 27. Simple Ring Armature with Two Coils in Parallel.

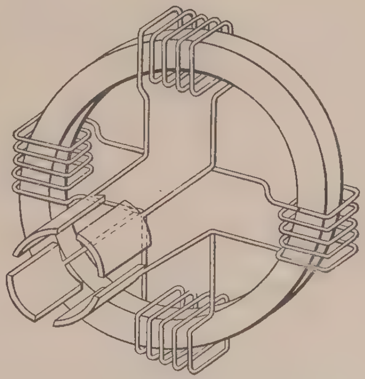


Fig. 28. Four-Part Ring Armature (Closed Coil).

The current obtained, however, from this arrangement has the disadvantage of being pulsating, as already shown. To give continuity to the external current we must multiply the number of generating coils, and also the number of commutator segments, arranging the coils around the armature so that one set will come into action before the other set goes out. If, then, we place upon the iron ring two additional sets of coils at right angles with the first set, as in Fig. 28, one set will be in the position of maximum activity when the other is in the position of least action; and Fig. 29 will represent the resulting external e. m. f. and current, which, although continuous (*i.e.*, never becoming zero), is not quite steady, having four slight undulations per revolution. By increasing the number of coils and commutator segments to a hundred or more, an external current can be obtained in which no undulations can be detected except by the telephone.

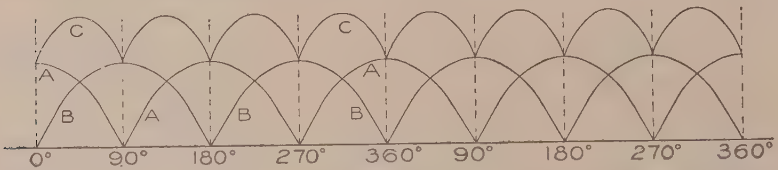


Fig. 29. Curve of E. M. F. and Current Generated by Armature Arrangement of Fig. 28.

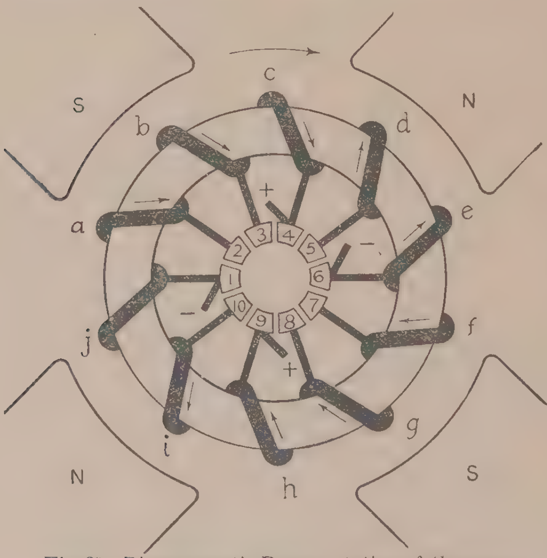


Fig. 30. Diagrammatic Representation of Gramme Ring Winding.

On examination of the winding represented in Fig. 28, it is apparent that the four coils are wound in series, the end of the first being connected to the beginning of the second, and so on, the end of the fourth being finally connected to the beginning of the first—the whole of the winding constituting, therefore, a single, closed coil. Also, it may be noted that the beginning of one coil and the end of preceding one are connected to the same commutator bar. In the practice the commutator is usually made up of a number of parallel

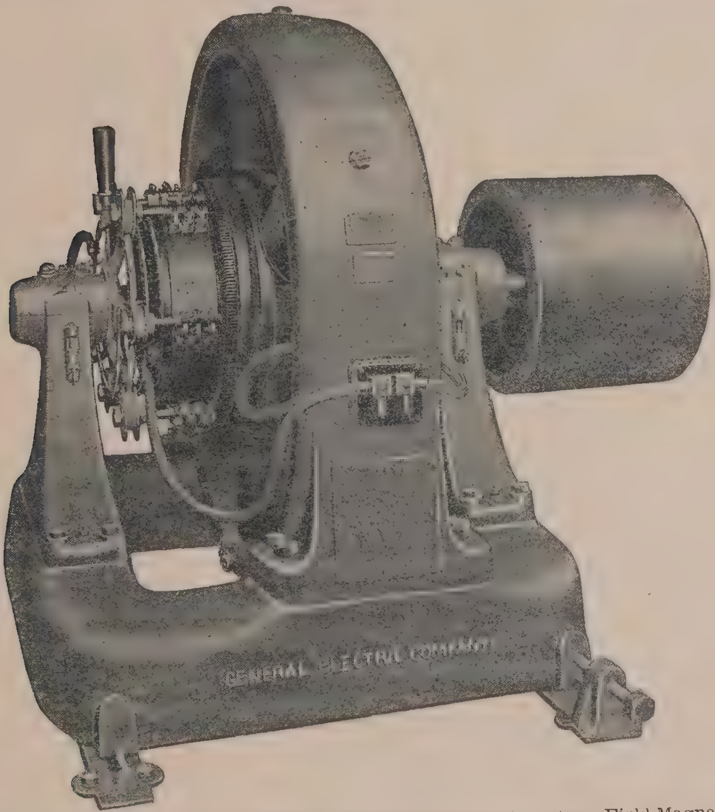


Fig. 31. Typical 6-Pole Belt-Driven Generator, Showing Armature, Field-Magnets, Commutator, and Brushes.

bars of copper set around on, and separated from each other by, insulating material; and the armature is made up of a number of sections as in Fig. 30, which represents a Gramme ring winding. This, and other windings, will be treated more fully later.

Organs of Continuous-Current Dynamos. We have seen that the dynamo in its simplest form consists of two main portions—an *armature*, which in revolving in a magnetic field generates an e. m. f.

in the conductors wound upon it; and a *field-magnet*, whose function it is to provide a flux for the conductors to cut as they revolve. These two parts are always present in all generators, whether for continuous current or for alternating current; and they are easily distinguished (Fig. 31). In almost all continuous-current machines, the field-magnet is a comparatively simple electromagnet which remains stationary; the armature, however, is more complex and usually rotates. In addition, we have seen that continuous-current machines require a commutator, while alternating-current machines are provided with *collecting* or *slip rings*. In either case, brushes are required to connect the revolving commutator or collector rings to the external circuit.

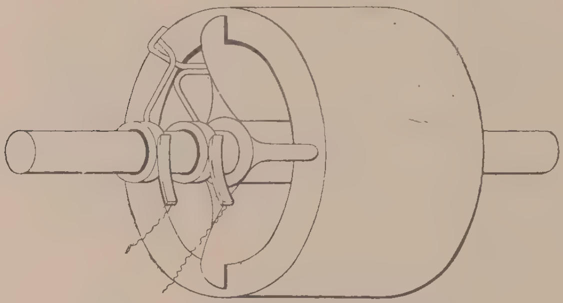


Fig. 32. Armature of Gramme Ring Type.

In continuous-current machines the field-magnet, being usually stationary, is combined with the bearings and bed-plate to form the frame of the machine. Similarly, the armature and commutator are supported by a spider and shaft, which rotate in the bearings attached to the frame. The complete machine comprises, in addition, various other mechanical parts taken up in detail later.

Armatures. Any electrical conductor—as, for example, a simple coil of wire—revolving in a magnetic field so as to cut the flux, would act as an armature and tend to have an e. m. f. generated in it. In order to obtain a practically steady direct current, together with maximum effect for a given amount of material, and to secure compactness, convenience of working, and other practical conditions, armatures have resolved themselves into the following types, although, theoretically, any figure of revolution around which coils are placed symmetrically, would answer:

(1) *Ring armatures*, in which the coils are grouped upon a ring core of iron whose axis of symmetry is also its axis of rotation.

(2) *Drum armatures*, in which the coils are wound longitudinally over the surface of a drum or cylindrical iron core.

(3) *Pole armatures,* in which the conductors are wound around radial iron cores projecting outward from a central hub.

(4) *Disc armatures,* in which the conductors are arranged in the form of a flat disc the plane of which is perpendicular to the axis of rotation, and usually not comprising an iron core.

The *ring armature* was first employed by Pacinotti in 1860, and described by him in 1865; but it is commonly known by the name of *Gramme,* the French electrician, who reintroduced it in 1870. Gramme wound the coils around the entire surface of the annular core, which he made of varnished iron wire in order to reduce the wasteful effects of eddy-currents; while Pacinotti had the coils wound between projecting teeth upon an iron ring. In ring armatures, the parts of the copper winding which pass through the interior of the ring do not cut any flux, and so are inoperative unless there are pole-pieces of the field-magnet projecting internally, which is not usually the case in practice.* Hence the ring type of winding offers a certain amount of wasteful resistance, which, however, can be made small compared with the resistance of the external circuit. Fig. 32 represents an armature of the Gramme ring type as generally used, although some machines are so designed as to have the outside of the ring act as a commutator, the current being collected directly from the winding by brushes which trail on the periphery of the ring, the inner parts of the conductors cutting the flux. Fig. 33 shows a completely wound Gramme ring armature.

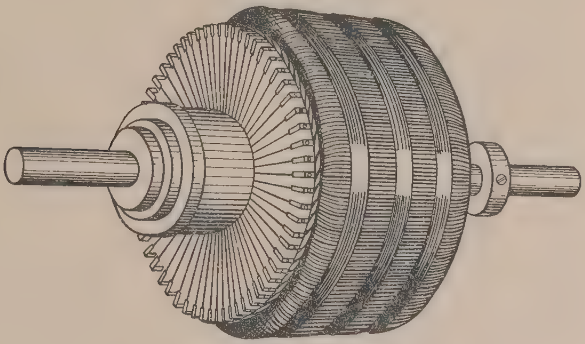


Fig. 33. Ring Armature of Gramme Dynamo.

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*In case of magnetic leakage through the opening in the ring core, the internal parts of the winding would produce an e. m. f. in the opposite direction to that generated by the outer sections, thus decreasing the effective voltage.

Drum armatures were introduced by Siemens, who wound cores of iron wire upon a frame of non-magnetic material. In their complete form, they were first brought out in 1871 by Von Hefner Alteneck, and improved later by Weston and others. As seen from Fig. 34, this type is even simpler than the ring, and consists in placing the elementary loop before described upon a supporting cylinder of magnetic material, so as to reduce the magnetic reluctance of the gap between the two faces of the field-magnet poles. This type of armature is almost exclusively used for continuous-current machines of to-day. In Fig. 35 is shown a partly-wound drum armature.

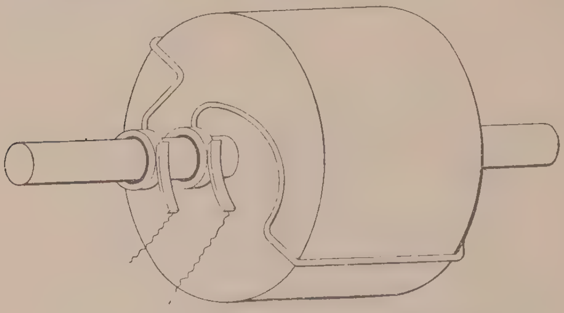

Fig. 34. Illustrating Method of Drum Winding.

Pole armatures—those having the coils wound upon projecting poles—were devised by Allan, Lontin, Weston, and others. They were used in Lontin's machines, as shown diagrammatically in Fig. 36. Owing, however, to the great self-induction thus introduced into each section of the winding, and the consequent sparking at the commutator, these machines were not successful. Pole armatures are to some extent used in alternating-current generators.

Disc armatures, illustrated in Fig. 37, have never been very widely used. The interesting feature of this type is the fact that there is no necessity for magnetic conducting material between the two faces of the field-magnet.

Armature Cores. The function of the armature core is twofold: it supports the generating conductors, and carries the flux from one face of the field-magnet to the other face. On account of its high permeability and its great strength, iron is by far the best material for armature cores. We have seen, however, that when a mass of iron (or other conductor) is rotated in a magnetic field, wasteful eddy currents are set up in the mass. In order to reduce them as much as possible, it has become the practice to build up armature cores of thin soft iron or mild steel discs, insulated from each other by varnish, rust, or paper. These discs are arranged to have their planes parallel to the direction of the flux and perpendicular to the flow of eddy-currents. Solid cores of metal should on no account be used in any armature.

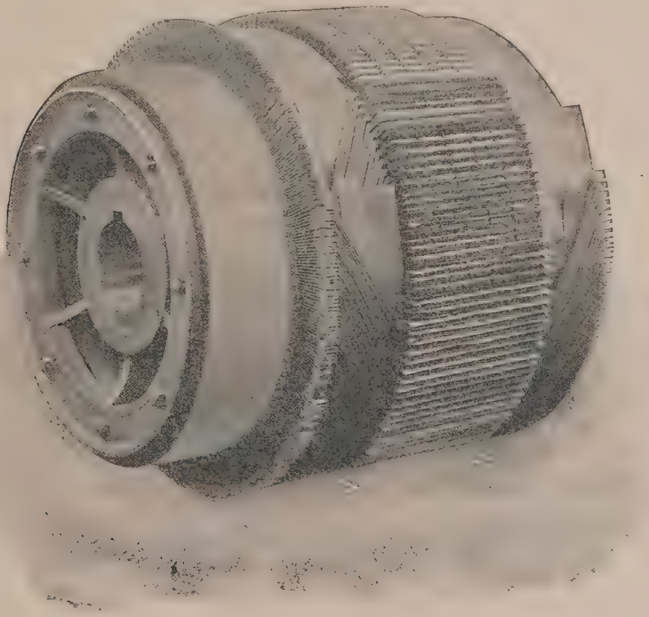

Fig. 35. Partly-Wound Drum Armature.

Field-Magnet Excitation. In order to generate an e. m. f. in the armature conductors, they must cut a flux. This flux is supplied by a magnet, and may be excited therein by five simple methods. These methods may be grouped under two headings, according to whether the armature of the machine furnishes the magnetizing current or m. m. f. required, or whether it is provided from some other source.

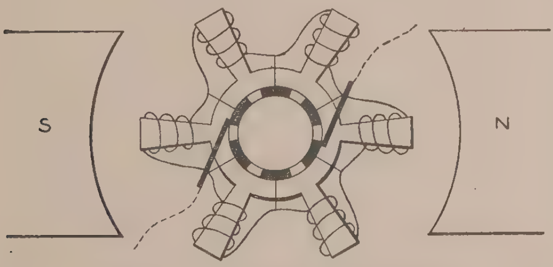

Fig. 36. Armature of the Pole Type.

(1) *Magneto-Machine.* In this type of generator, historically the first, the flux was provided by a permanent magnet as shown diagrammatically in Fig. 38. This method has the disadvantage of requiring a much bulkier machine in comparison with the methods to be described later, since permanent magnetism cannot be maintained at the high flux-density which may be produced by an exciting coil. It has, however, the advantages of simplicity and constancy, but is used only in the smallest of generators employed for example, to furnish current for ringing bells, for ignition in internal-combustion engines, etc.

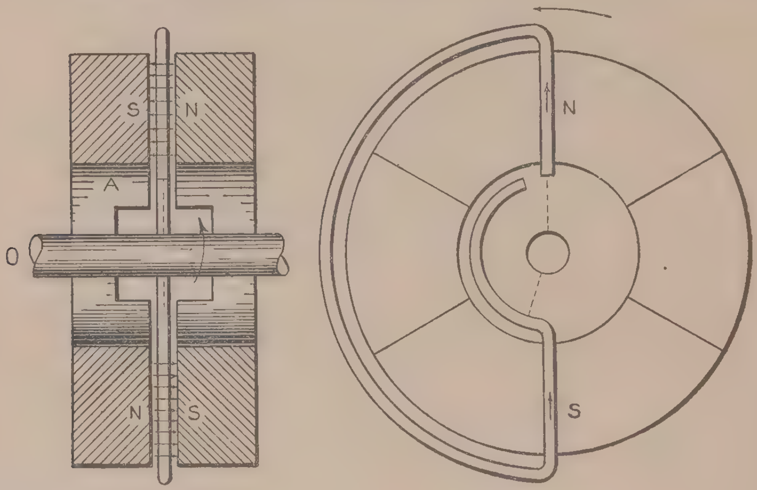

Fig. 37. Armature of Disc Type with Two Inductors in Series.

(2) *Separately-Excited Generator.* The next step was to excite the field-magnets by means of a coil fed from some source of electrical energy other than the generator itself. This method, outlined in Fig. 39, produces the same results as the magneto method, without the disadvantage of great bulk. It requires, however, a separate machine or battery for excitation purposes solely, and the method is not employed in continuous-current practice, except where many machines are in operation, or where their terminal voltage exceeds 800 volts. It is largely employed in exciting the fields of alternating-current generators, since an alternating current will not produce a unidirectional magnetic field.

In either of the methods just mentioned, the e. m. f. of the machine may be governed in three ways—namely, by (*a*) altering the speed of rotation of the armature; (*b*) by varying the number of effective conductors by moving the brushes; and (*c*) by changing the magnetic flux through the armature. The latter is altered in the case of magneto-machines by shunting the flux away from the armature through an auxiliary piece of iron. In the case of separately excited machines, the flux is varied by regulating the exciting current or the number of turns of the solenoid.

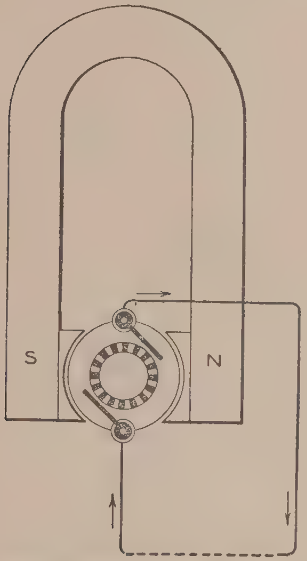

Fig. 38. Diagrammatic Representation of Magneto-Generator.

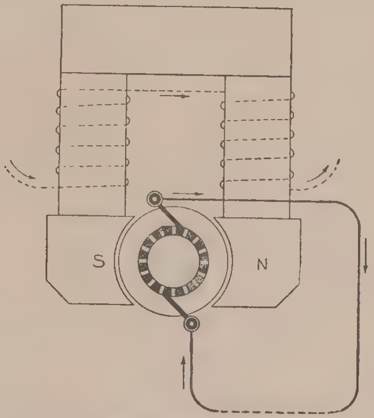

Fig. 39. Diagrammatic Representation of Separately-Excited Generator.

Generators of the continuous-current type may be made *self-exciting* by either of four methods. The whole current supplied by the machine to the external circuit may be passed through the solenoid, or a part of the total current may be passed through the field-winding; or two field-windings may be employed, one traversed by the load current and the other by the shunt current; or, finally, the field-exciting current may be produced by an e. m. f. generated by a separate winding on the armature of the generator.

(3) *Series Dynamo.* The series continuous-current generator outlined in Fig. 40 has but one circuit. It has, however, the disadvantage of not starting to generate until a certain speed has been reached or unless the resistance in the external circuit is below a certain

limit. It also is liable to become reversed in polarity, thus unfitting it for electrolytic work. Any increase in its external resistance, at a given speed, diminishes the current stream that excites the magnetic circuit, thereby lowering the e. m. f. Conversely, reduction of external resistance tends to increase the e. m. f. of the machine until the *IR* drop and the armature reaction become so large that the available voltage falls more rapidly than the field stream increases. The only series generators actually employed supply *arc lamps in series*, and are provided with automatic regulators to maintain constant current; hence the external voltage and power are directly proportional to the external resistance.

(4) *Shunt Dynamo.* In the shunt-wound generator, Fig. 41, only a small part of the current in the armature passes through the field winding. The field-exciting circuit F_{sh} has, therefore, a relatively high resistance compared with that of the external circuit. This machine is tolerably self-regulating within certain limits, when properly designed; but if overloaded, its internal actions are such as to reduce its generated e. m. f. to zero. Its polarity never reverses of itself; and although it is a trifle more expensive to buy than the corresponding series machine, its self-regulating properties more than overbalance this. The amount of energy required for excitation in either series or shunt field-windings for identical machines, is precisely the same, since to produce a given flux (as shown in the discussion of the magnetic circuit) demands a definite number of *ampere-turns.* In the series machine, the *turns* of wire are few in number, while the current in *amperes* is relatively large. In the shunt type, the reverse is the case.

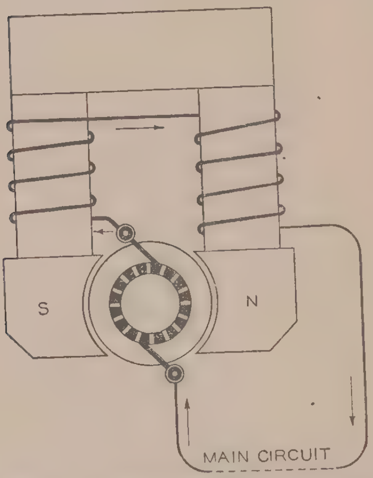

Fig. 40. Diagrammatic Representation of Series Continuous-Current Generator.

(5) *Separate-Circuit, Self-Exciting Generator.* The third type of self-exciting machine is that in which the field circuit is supplied by only part of the armature, or by separate windings on the armature,

as represented in Fig. 42. This arrangement is adopted for A. C. generators and for D. C. machines in which the e. m. f. generated is over 800 volts, since it is undesirable to apply such voltage to field excitation. In effect, however, it is almost the same as the separately excited machine (No. 2, above).

Generator Regulation. In all the simple methods of field excitation just described, the e. m. f. generated by the dynamo varied more or less with load. If the load were constant (*i.e.*, if the same number of lamps were being supplied all the time), the generator could be designed to give a predetermined terminal voltage. But under usual working conditions, the load connected to an electric generator—such as lamps, motors, or other devices—is continually changing, so that it is essential to provide some device whereby its e. m. f. may be varied to suit the varying load. The generated e. m. f. is the sum of the terminal voltage and that lost in overcoming internal reactions, the latter quantity varying with load. As stated previously, there are three methods for regulating the generated e. m. f. of the dynamo—namely, by varying the speed of rotation of the armature, by varying the magnetic flux, and by changing the number of effective or active armature conductors.* Of these three possible methods, however, the only one utilized is that of varying the magnetic flux, it having been found more convenient to regulate the prime mover for constant speed than for speed increasing with load, while the method of changing the effective armature conductors by shifting the brushes is conducive to bad sparking at the commutator. As has been noted, the most advantageous way to vary the magnetic flux is to vary the current in the energizing coils.

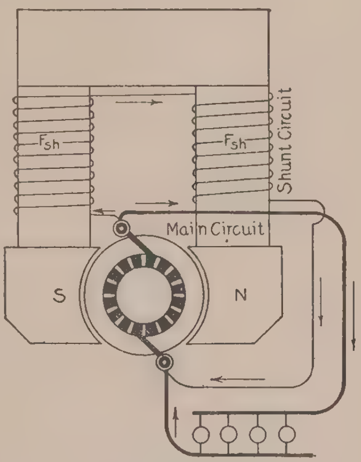

Fig. 41. Diagrammatic Representation of Shunt-Wound Generator.

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*The expression "active armature conductors" refers to those conductors which are actually cutting flux and generating an e. m. f. at any instant.

Since the current in the field-exciting coils is dependent upon the e. m. f. impressed at their terminals and upon their ohmic resistance, we can increase the magnetic flux by decreasing the resistance of the field-exciting circuit or by increasing the terminal voltage impressed there. Also, the flux may be made to increase with load, by passing the external current of the generator through a few turns of thick wire, called *series turns* or *compounding turns*, placed upon the field-cores. The first method is usually non-automatic, and is applicable to shunt and separately excited machines; the second is applicable to separately excited machines; and the third, to both types; and a generator thus equipped is called a *compound generator.*

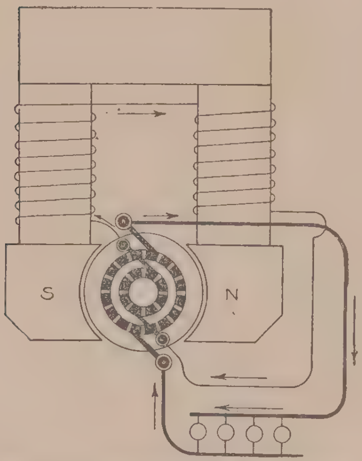
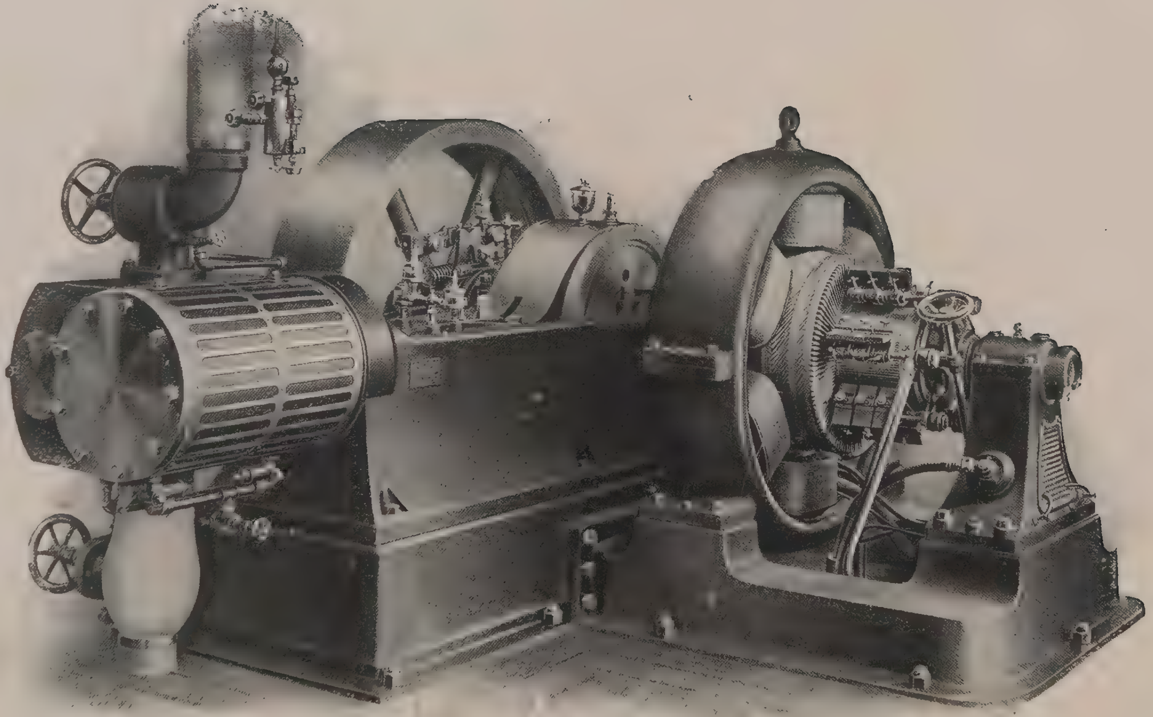


Fig. 42. Diagrammatic Representation of a Separate Circuit, Self-Exciting Generator.

Methods of Compounding. (1) *Separate and Series* (Deprez). The connections are shown diagrammatically in Fig. 43, a separate source of e. m. f. being used to produce the initial and constant excitation, while the external current of the machine is led through a series winding, thus compensating for the internal drop of the generator to any desired degree, even *increasing* the terminal voltage with load if desired.

(2) *Shunt and Series.* By far the most widely used of all compounding schemes, however, is the one in which series turns are added to the plain shunt winding, as illustrated diagrammatically in Fig. 44. By properly proportioning the ampere-turns in the shunt and series coils, the terminal voltage-load curve may be made to take any desired form. For instance, it may be made constant, increasing or decreasing throughout the rated load range of the machine. This arrangement will be considered in detail later on.

(3) *Booster Method.* This consists essentially of an auxiliary generator in series with the main machine, the e. m. f. of the former being low; and since its field winding is in series with the external circuit, it will automatically regulate the voltage of the combination in accordance with the load



HORIZONTAL ENGINE DIRECT-CONNECTED TO GENERATOR.

New York Safety Steam Power Company.

(4) *Miscellaneous Methods.* If the generator armature be wound according to a special scheme devised by Sayers,* the field excitation may be produced by a simple shunt winding, and a compounding effect produced by giving the brushes a backward lead. Other methods of compounding may be found in S. P. Thompson's "Dynamo-Electric Machinery."

Actions in the Armature. Thus far we have considered the armature and the field of the generator separately, assuming that the former did not affect the latter. It is found, however, that when the armature of a generator or motor is carrying current, its action is not the same as when it carries no current, owing to the distortion of the field flux by the magnetization of the armature. In order to study the effects produced, we shall consider a dynamo of the simple bipolar type (Fig. 45) with a ring armature, when the machine is operating without and under load.

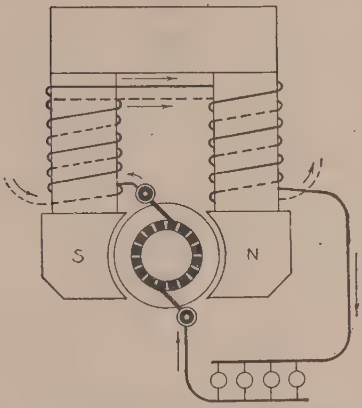


Fig. 43. Separate and Series Method of Compounding.

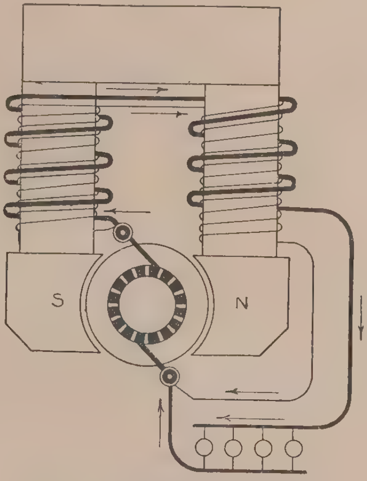


Fig. 44. Shunt and Series Method of Compounding.

Suppose the armature to be rotating clockwise, when viewed from the commutator end, and that the north pole of the field-magnet is at the right of the armature, the south pole being on the left, as in Fig. 46. The flux will then pass from right to left through the armature; and the e. m. f. generated in the moving conductors of the armature is, in accordance with Maxwell's law, as follows:

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* See E. Arnold's *Gleichstrommaschine* (Erster Band, Berlin, 1902), pages 417, 449, *et seq.*

In all the conductors which are ascending, the generated e. m. f. is directed toward the observer; while in all the descending conductors, the generated e. m. f. is directed away from the observer. If the circuit through the armature is closed, the generated e. m. f. will produce a current flowing in the same direction; and in Fig. 46 the current-flow in the armature is toward the top and away from the bottom on both sides. This result is obtained when the armature is wound right-handedly, being the opposite if the winding is left-handed. With a drum-wound armature, the result is the same; but the diagram is more complex on account of the end connections.

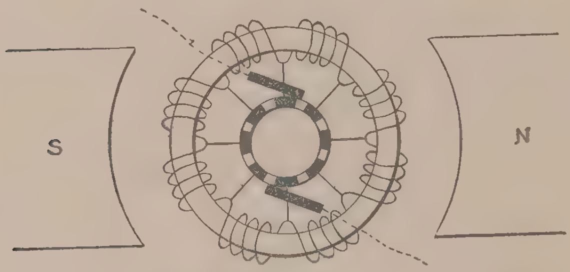

Fig. 45. Diagrammatic Representation of Simple Ring Armature.

It will be noted that the path of the current is from brush to brush, through each of the armature coils, without going to the commutator except where it passes out to or returns from the external circuit. We have seen, however, in the ideal dynamo, that the e. m. f. generated in an armature coil is proportional to the time rate at which the flux is cut. In the case illustrated in Fig. 47, no two armature coils are cutting the same amount of flux at any given instant, so that the voltage generated in each coil depends upon its position in the field. Since one-half of the coils are connected in series between the brushes, the total difference of potential (p. d.) measured at the latter will at any instant be the sum of the instantaneous e. m. f.'s generated in the individual coils.

If the field were uniform, it is plain that the flux cut at a given instant by any one coil would be proportional to the sine of the angle which it makes with the direction of the field at that instant; so that if we plot the values of these instantaneous potentials as ordinates, and the corresponding angles as abscissæ, we obtain Fig. 47.

Thus it is seen that the p. d. obtained at the brushes may be compared to that obtained at the terminals of a battery connected as shown in Fig. 48, each cell representing an armature coil and being supposed to supply an e. m. f. equal to that generated by the coil it replaces. The terminal voltage will then be obtained by adding all these potentials between the 0° and the 180° positions in Fig. 47, or integrating the voltage curve between these limits, the negative part being exactly equal to the positive half if the dynamo is symmetrical. The sum thus obtained grows slowly at first, then rapidly, and slowly again as it reaches its highest value, repeating this program in the other half-circumference. These facts are shown at reduced scale in Fig. 49. In the actual dynamo, this integration is effected because the coils are connected in series; and it is possible to demonstrate this experimentally.

Exploration of Potentials around a Commutator. Several more or less simple ways of showing the distribution of the generated e. m. f. around the commutator of a dynamo, have been suggested,* but only one, Mordey's method, will be taken up here. It consists in connecting one terminal of a voltmeter, preferably an electrostatic one, to one brush of the machine, and the other terminal to a small pilot brush *b* (Fig. 50), which can be moved from point to point around the commutator. The armature of the generator is then rotated at its rated r. p. m. (revolutions per minute); and, starting at the brush *N*, *b* is placed in successive positions around the commutator, the voltmeter reading in each position being noted, together with the corresponding angular situation of *b*.

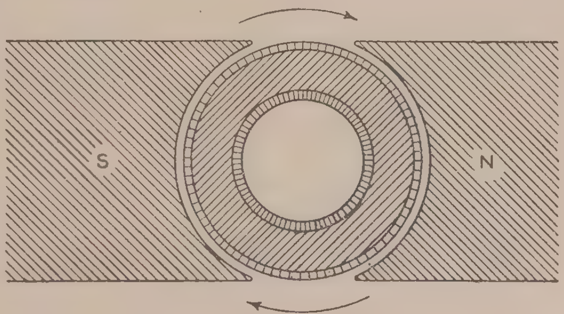

Fig. 46. End View of Ring Armature in Bipolar Field.

These results, plotted with the voltage readings as ordinates and the corresponding values of angular situations of *b* as abscissæ, are as represented in Fig. 51, when the armature is carrying no current. The curve so obtained is not usually a true sine curve in commercial machines, because the magnetic field in which the armature rotates is not uniform. Also, we shall see later that when the armature carries a current, its presence causes a further distortion in the distribution of the flux. Furthermore, the setting of the brushes or an injudicious shaping of the pole-pieces will cause irregularities to be present in this curve, examples of which have been given by Von Gaisberg*, Kohlrausch**, M. E. Thomson***, Ryan†, and Shephardson††.

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*See S. P. Thompson's "Dynamo-Electric Machinery," Vol. I. (N. Y., 1904), page 204.

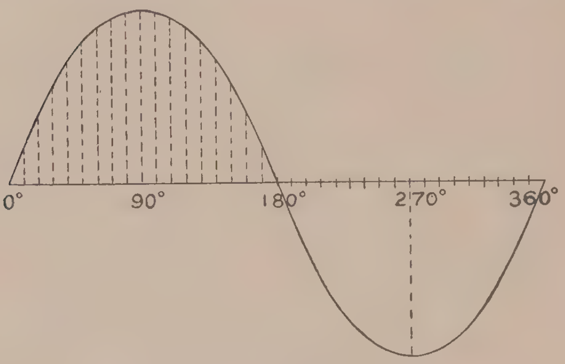

Fig. 47. Curve of Induced E. M. F.

Reactions in the Armature. This leads us to consider the reactions of the armature when the generator is operating, which are manifested in many ways, the most important being:

(1) A tendency to *cross-magnetize* the armature.

(2) A proneness to spark at the brushes.

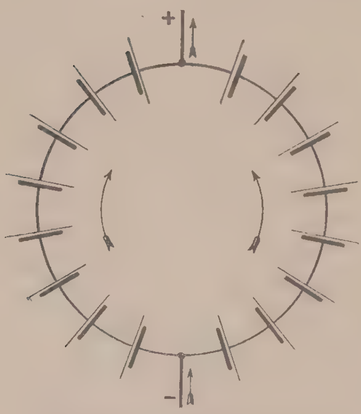

Fig. 48. Battery Analogy of Simple Dynamo.

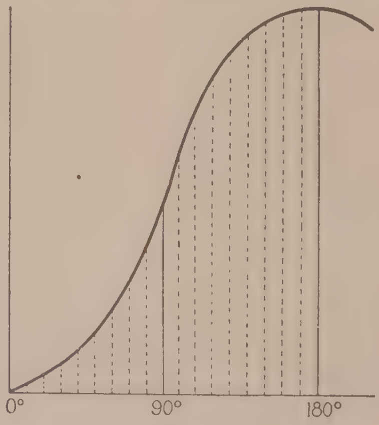

Fig. 49. Integrated Curve of Potentials.

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* *Elektrotechnische Zeitschrift*, vii 67, Feb. 1886.

** *Centralblatt für Elektrotechnik*, ix 419. 1887.

*** "Electrical World," xvii 392, 1891.

† Trans. Amer. Inst. Elec. Engrs., vii 3, 1890.

†† "American Electrician," x 453, 1898.

(3) Variation of the neutral point of the armature with the amount of current.

(4) The consequent necessity of shifting the brushes.

(5) A resultant tendency to demagnetize the armature.

(6) Losses due to eddy currents in the pole-pieces, armature core, and coils.

(7) A resulting difference between the input and output.

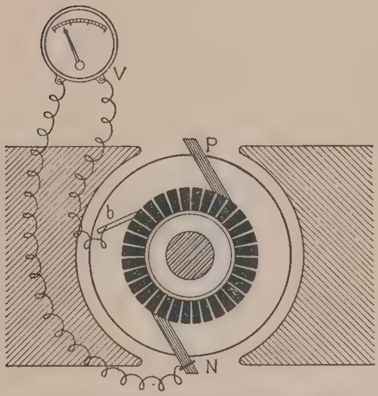

Fig. 50. Mordey's Method of Exploring Potentials around Commutator.

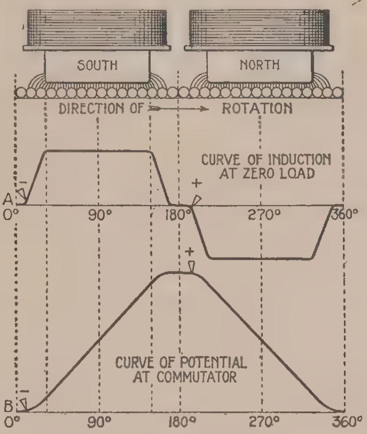

Fig. 51. Undistorted Field.

As these reactions have much effect upon the operation of the commercial machine, they will be considered in detail.

Cross-Magnetizing Effect of Armature Current. We have seen from Fig. 48 and the accompanying text, that the armature of a generator may be likened to a combination of voltaic cells; but the armature carrying current manifests a magnetic effect absent in the latter.

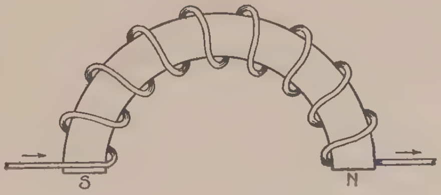

Fig. 52. Poles on Half-Ring.

If we consider the solenoid of page 4 to be bent around so as to form a semicircular ring, and to have inserted into it an iron core of the same form, one end of this core would act as a north pole, and the other end as a south pole, when current circulates in the winding (Fig. 52). By taking an exactly similar semicircular ring and placing the two together so that their north poles and the south poles are respectively coincident, we are able to reproduce the magnetic effect of current flowing in the armature. That is, when the generator supplies energy to the external circuit, the armature has poles produced in it corresponding to the brushes—namely, where the current enters and leaves the winding. This magnetization of a simple Gramme ring armature (Fig. 53) is indicated in Fig. 54, the general direction of the flux being through the armature core along both paths from *a* and *b* to *n* and *s*, where it emerges into air, forming respectively the poles of the armature. The main portion of this flux returns outside the ring, while a small portion passes across the interior. This latter portion is extremely small in commercial machines, on account of the presence of large masses of iron in the pole-pieces which are outside.

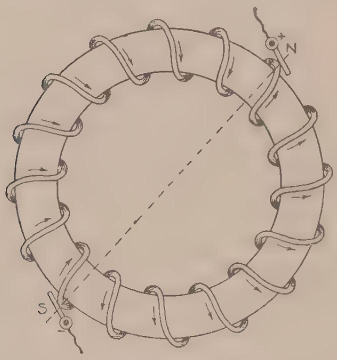

Fig. 53. Circulation of Current around Ring Armature.

The cross-magnetization of the armature produces a distortion of the flux in it; but this would have small effect upon the e. m. f. if the line of commutation did not also change with the armature current. This change necessitates the moving of the brushes; and then the armature not only produces a cross-magnetizing effect, but also has a demagnetizing tendency. It is this latter which diminishes the generated e. m. f.

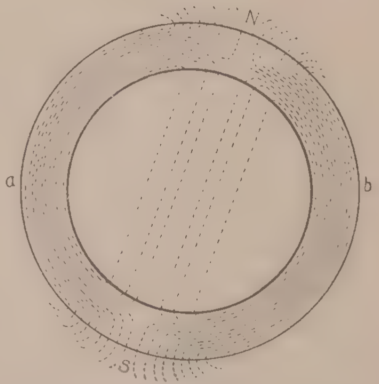

Fig. 54. Magnetization Due to Armature Current.

In order to study the result, let us suppose the simple bipolar dynamo of Fig. 45 to be arranged so that current may be passed through its field windings, its armature when rotating, or through both. When the field alone is excited, the flux distribution will be substantially as indicated in Fig. 55—that is, quite uniform in the pole-pieces, air-gaps, and armature. If, now, the field-exciting circuit be opened, and if a current be supplied to the rotating armature equal to its rated load current, the flux distribution shown in Fig. 56 will exist. By combining these two conditions of the flux, there is produced the distortion shown in Fig. 57, which is the resultant flux distribution in the generating portion of the machine. The magnetism is distorted in the direction of rotation, as if the armature tended to draw after it the flux issuing from the field-poles. But this is not the physical fact, because we find that in electric motors the flux is distorted in a direction *opposite* to that of the rotation of the armature. In fact, the flux-distribution is the same whether the armature turns one way or the other, or not at all. On account of this flux distortion, brushes must be set, not midway between the field-poles, but, in the case of generators, somewhat ahead of this line of symmetry. Consequently the armature m. m. f. will be oblique to that due to the field-magnet, and a further distortion will result.

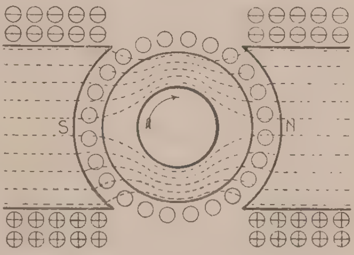

Fig. 55. Flux Due to Field Alone.

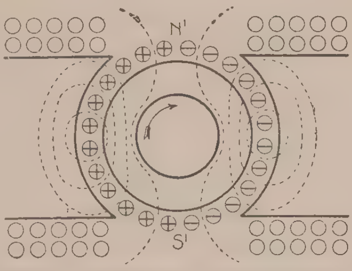

Fig. 56. Flux Due to Armature Alone.

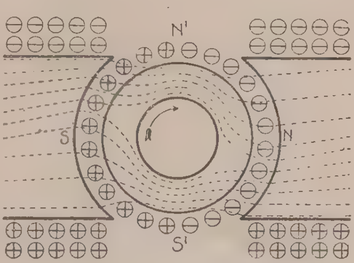

Fig. 57. Flux Due to Field and Armature.

These relations are shown vectorially in Fig. 58, the line OF representing in direction and magnitude the flux due to the field-magnet, and the line OA' the direction and magnitude of the flux set up by the armature current with the brushes in the line of symmetry or vertical position. In this case, OR' represents the resultant flux in value and direction, and the brushes should be shifted to the line OA'', perpendicular to OR'. The armature component of the flux also shifts to this direction, but with unchanged magnitude because the ampere-turns and other relations of the magnetic circuit are not varied. This will produce a new resultant OR'', and the brushes should be shifted until the line of commutation OA is approximately perpendicular to OR, the final flux vector. These conditions are also represented in Fig. 59, OF being the field-magnet flux, OA the armature flux with the brushes shifted, and OR the resultant with the main line of the flux (PQ) as an extension of it.

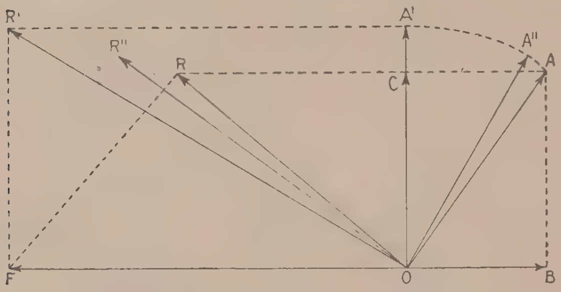

Fig. 58. Magnetic Reactions in Armature.

In the case of drum-wound armatures, the phenomenon is similar but not so easily traced. In consequence of the overlapping of the end-connections, the magnetizing effects of some of the coils are neutralized, and as a result the production of poles is not so marked. Neither can there be any internal field. As a matter of fact, drum-wound armatures are not troubled to the same extent with induction effects as are ring-wound ones. With these exceptions, however, the facts here considered apply equally to drum-wound and ring-wound armatures.

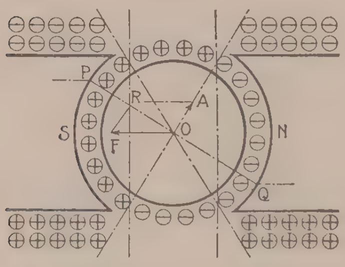

Fig. 59. Back and Cross Ampere-Turns.

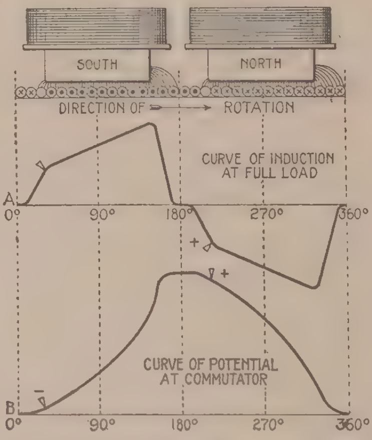

Fig. 60. Curve of Armature Distortion.

The distortion of the flux through the armature also produces a distortion in the wave of induction, as may be shown by exploring the potential differences around a commutator by Mordey's method, when the machine is carrying its rated load. Such a curve is shown in Fig. 60.

Sparking at the Commutator. On page 20 we have seen that the rotation of the armature in the field of the machine generates alternating currents in the conductors. A consideration of Fig. 57 shows that all the current flows toward the spectator in the conductors which are rising, and away from the observer in all the descending conductors, the brushes in this case being supposed present at N' and S'. Thus, when a coil passes under one of the brushes, the direction of the current in that coil is *reversed.* Owing to the fact that even a single armature coil possesses some self-induction, the current cannot change instantaneously; that is, a certain definite interval of time is required, dependent upon the self-inductive property of the armature coil, as well as upon its resistance. During this interval, and until the whole current can take the new path through the coil, a portion of the current continues to flow from the receding commutator bar, through the air, to the brush, in the form of a spark. It is the interruption of this latter current, as the commutator bar leaves the brush, that produces the spark.

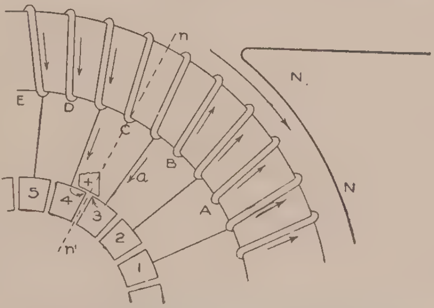

Fig. 61. Illustrating Requirements for Non-Sparking Condition of Commutation.

Commutation. In order to understand exactly what happens when a current is commutated, let us consider what takes place in one section of an armature winding, and at the two commutator bars attached to the latter, when the bars pass under a brush.

Fig. 61 shows a portion of a ring-wound armature with its coils *A*, *B*, *C*, *D*, and *E* connected to segments 1, 2, 3, 4, and 5 of the commutator, and a positive brush just beyond the leading tip of one of the pole-pieces. The line *nn′* represents a line drawn in space so as to cut the commutator at a point where the voltage between the brush and the bars thus passed through is zero. The brush is assumed placed in this line.

Now, before any given section of the winding reaches the brush shown in the figure, a current will be flowing in it in the direction of the positive brush; and after the section has passed the brush, the current, although reversed in direction, is still flowing towards the brush.

The figure shows the instant at which coil C is short-circuited by the brush through the commutator bars 3 and 4; and it is during the brief interval of this short circuit that the current in coil C must be reduced to zero, reversed, and then built up again in order that there shall be no tendency for a spark to form between the brush and the bar 3 at the instant they part.

As to the establishment of a reversed current in section C while it is short-circuited by the brush, it must be remembered that this coil is at this instant supposed to be occupying a position such that there is no e. m. f. being generated in it; that is, it is in a neutral position. In coils to the immediate left and right of coil C, however, e. m. f.'s are being generated in such a direction as to cause the resulting current to flow *towards* the brush. If, therefore, we move the brush forward—that is, in the direction of rotation—from its present position in the neutral line, the section short-circuited by that brush will be placed in a region where a p. d. will be generated between its terminals in such a direction as to assist the reversed current above mentioned. Also, the greater the forward lead—that is, the further away from the neutral line in the direction of rotation the brush is moved—the greater will be the p. d. so generated; so that by trial, a position of the brush may be found where the condition of sparkless collection is fulfilled.

The use of high-resistance carbon brushes tends to cause a decrease to zero of the current existing in the sections before they reach the brush, since the latter forms part of the short circuit. Their use also aids the establishment of the reversed current in the short-circuited section, before the brush and segment part company. This is due mainly to the contact resistance between the brush and the commutator, as follows:

The current flowing across the contact area of the brush and leading segment under it (in the figure, segment 3), produces a drop of potential there, which is small on account of the large area of contact, at the instant depicted. A moment later the brush is making better contact with segment 4, and poorer contact with segment 3, so that the voltage drop across the contact area of the brush and 3 has risen above that of the brush and 4. Hence a current will tend to flow from segment 3 to segment 4, as a reverse current through C, being produced by the difference of potential between them. This state is comparable to that of the ordinary potentiometer, where a "drop" acts as an e. m. f. in producing a current flow. The voltage resulting from this potential difference across the two contact areas mentioned, assists that tending to produce reversal.

Thus, as the commutator moves under the brush (assuming the latter to have a forward lead), the e. m. f. for reversal, the p. d. due to the varying contact area of the brush, and the resistance of the short-circuited coil, combine to reduce the current in the latter to zero, while the self-induction of the coil tends to prevent any change of the current in it.* This zero condition should occur when the areas of contact between the brush and the two (in this case) bars passing under it are equal. Then, when the segments leave this position, the p. d. between them will increase, thus assisting the direct e. m. f. (produced in the coil by the flux from the hindward pole-horn) in establishing a current in the coil in the reverse direction. Opposing this are the resistance and self-induction of the coil. With proper conditions, the various reactions mentioned may be so proportioned as to produce in the coil from which the short circuit is about to be removed, a current equal in amplitude and direction to that flowing towards it from the preceding coil. In the figure, coil

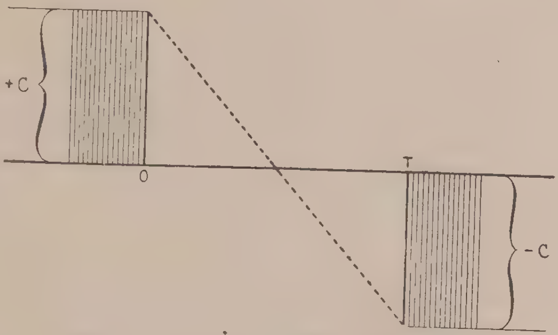

Fig. 62. Curve of Commutation—Ideal Case.

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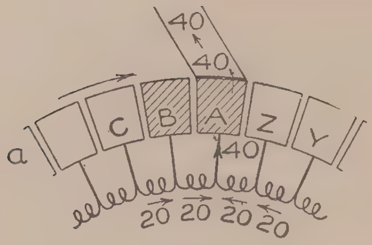
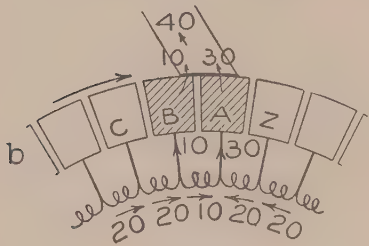
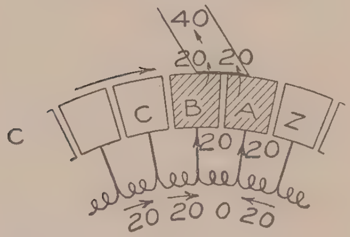
*See S. P. Thompson's "Elementary Lessons in Electricity and Magnetism," N. Y., 1903, pp. 466 *et seq.*



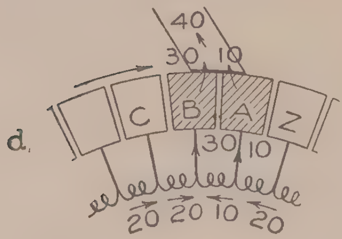
(*a*) Instant before Commencement of Commutation in Section *AB*.



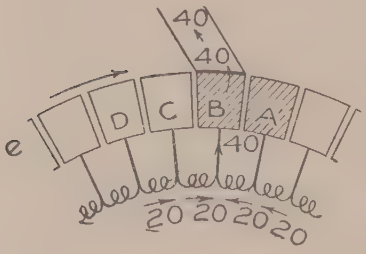
(*b*) End of First Quarter of Period of Commutation in Section *AB*.



(*c*) End of Second Quarter of Period of Commutation in Section *AB*.



(*d*) End of Third Quarter of Period of Commutation in Section *AB*.



(*e*) Commutation in the Section *AB* Completed.

Fig. 63. Process of Commutation.

C would be the one to have the short circuit removed; and *B*, the preceding coil. Then segment 3 will pass out of contact with the brush without a spark attempting to follow.

Resistance during Reversal. Let us assume that during commutation the brush contact resistance is inversely proportional to the area of contact. Then, in the ideal case, where the coils of the armature are devoid of resistance and inductance, the curve of commutation will be as shown in Fig. 62, *C* representing the value of the current to be commutated, *O* the instant when commutation commences, and *T* the period requisite for this action. Here the current gradually diminishes to zero at the middle of the commutation period, and reaches its negative maximum value at the end of the time *T*. This process is shown in detail in Fig. 63, the brush being wide enough to span one commutator bar.

In this case 20 amperes flow from either side of the armature to the brush, the latter leading away 40 amperes. If we suppose the brush area to be one square inch, then, when the commutator is in the position indicated by Fig. 63 (*b*), the area of contact of the segment *A* is reduced to $\frac{3}{4}$ square inch, while that of the segment *B* has become $\frac{1}{4}$ square inch, so that 10 amperes will flow into the brush from *B* and 30 amperes from *A*, the additional 10 amperes through the latter coming from the short-circuited coil. When the commutator has moved forward so that the area of contact of each brush is the same—that is, $\frac{1}{2}$ of a square inch—*A* and *B* will each pass 20 amperes to the brush from either side of the armature, the coil undergoing commutation carrying no current at this instant (see Fig. 63, *c*). At the end of the third quarter of the commutation period, the commutator has reached the position shown in Fig. 63 (*d*), the area of contact of segment *A* with the brush being $\frac{1}{4}$ of a square inch, while that of *B* is $\frac{3}{4}$ of a square inch. Hence *A* will contribute 10 amperes and *B* 30 amperes to the brush, the coil undergoing commutation now carrying a current in the direction reverse to that indicated in Fig. 63 (*b*), and in the same direction as the current in the coils on the right. At the end of the commutation period, the current in coil *A–B* has increased to the full value of that flowing in its right-hand neighbor; and when the brush and segment *A* part company no spark will result.

Fig. 62 shows the variation of the current during this period, if we neglect the resistance and inductance of the armature coils. It therefore remains to consider the effect of these reactions.

Commutation Curves. If the resistance of the armature coils be not negligible in comparison with the contact resistances, then the current collected will not be rigidly proportional to the areas of contact. For, suppose that in Fig. 63 (*b*) the contact resistance over *A* is 0.04 ohm, and that that over *B* is 0.12 ohm; then, if the resistance of one coil of the armature be taken at the exaggerated value of 0.01 ohm, 29.6 amperes will go through *A*, and 10.4 amperes will pass through *B*. In other words, the presence of resistance in the coils of the armature reduces the ratio of currents during the first half of the commutation period, and increases this ratio during the second half. This is shown graphically by the curved line in Fig. 64, the straight line indicating the ideal case.

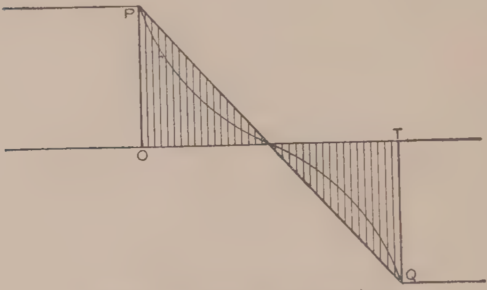


Fig. 64. Curve of Commutation.

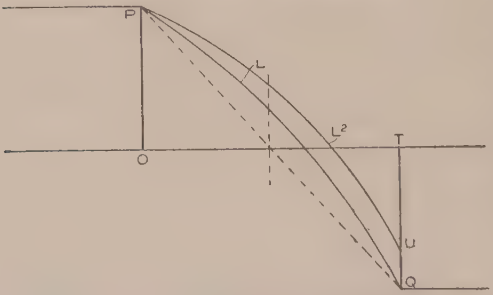


Fig. 65. Curve of Commutation, with Self-Induction.

The effect of self-induction, although not easily shown quantitatively, would modify the ideal current curve as indicated by PL^1Q in Fig. 65, PL^2U showing the result obtained with increased self-induction. Self-induction tends to retard any change in the current, so that the same is not completely reversed at the end of the commutation period. At the last instant, then, as the surface of contact between the segment *A* and the brush diminishes to zero, the contact resistance rises with extreme rapidity. The product of this resistance and the still uncommutated part of the current, will constitute a p. d. between the retreating segment *A* and the tip of the brush. This p. d., represented graphically by *QU* in Fig. 65, tends to set up a spark, and may be briefly called the *sparking* or *maintaining* e. m. f.

The resulting commutation curve for any machine is made up of these two effects, the quantity of each depending upon the design, and of some details at present obscure. Messrs. Everett and Peake* found experimentally that the curve had the form shown in Fig. 66. Curve *A* indicates the initial rise which may obtain at light loads, with an oval resultant at the negative end. *B* illustrates under-commutation with insufficient lead. *C* shows, with increased load, a rapid reversal at the beginning of the commutation period, but under-commutation toward the end. *D* represents a gradual fall of the current, which slackens toward the end.

Effect of Increasing Breadth of Brush. Increasing the breadth of the brush not only lengthens the period of commutation, but also permits commutation to start in one coil before the preceding coil has entirely passed through this stage.

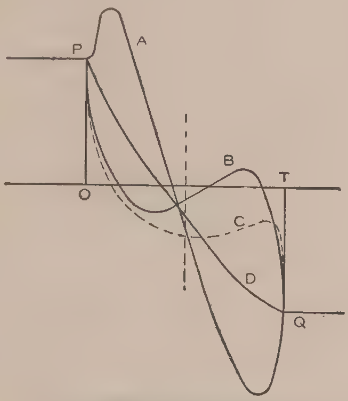


Fig. 66. Curve of Commutation Observed by Everett and Peake.

In Fig. 67, let us assume the brush to have an area of 3 square inches, and that it can completely cover two segments at one time, the current collected by the brush being 120 amperes. Then Fig. 67 (*a*) shows the state of affairs when the segments *A* and *Z* are under the brush. An instant later, the commutator, in moving clockwise, starts to uncover segment *Z* and to cover segment *B*, so that at the end of the first quarter of the period of commutation, the result will be as indicated in Fig. 67 (*b*), for the ideal case. Similarly, in Fig. 67, *c*, *d*, and *e* represent respectively the conditions at the end of the second, third, and fourth quarters of the commutation period, the direction of current and its magnitude in each coil being indicated by arrows and figures. We see from these that the conditions of Fig. 63 (page 44) obtain throughout, the current in the short-circuited coils being zero at the middle of the period of commutation; so that we may conclude that the act of commutation is not altered by increasing the width of the brush.

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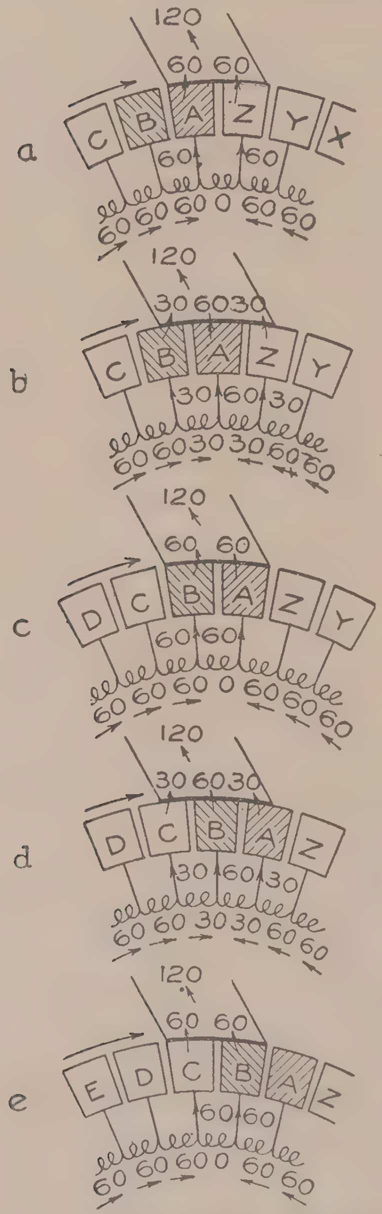
*See *Electrician*, London, Vol. 40, p. 461; Vol. 42, p. 328.



(*a*) Instant before Commencement of Commutation in Section *AB*

(*b*) End of First Quarter of Period of Commutation in Section *AB*.

(*c*) End of Second Quarter of Period of Commutation in Section *AB*.

(*d*) End of Third Quarter of Period of Commutation in Section *AB*.

(*e*) Commutation in Section *AB* Completed.

Fig. 67. Process of Commutation.—Brush Covering Two Segments

Summary of Results. The considerations above indicated as to means for controlling the sparking at the commutators of continuous-current machines, may be summed up as follows:

(1) Keep the inductance of the armature coils low, by decreasing the number of turns per commutator segment, by saturating the teeth, and by properly shaping the pole-pieces to produce a reversal fringe.

(2) Keep the volts per segment of the commutator low by having a large number of commutator segments.

(3) Control distortion of the main flux in order to have the field under the hindward pole-horn sufficiently strong.

(4) Properly dimension and design the commutator-brushes,* brush-holders, and other brush-gear, so as to permit the shifting of the brushes to the proper position, and to enable the brushes to make contact with the commutator at all times.

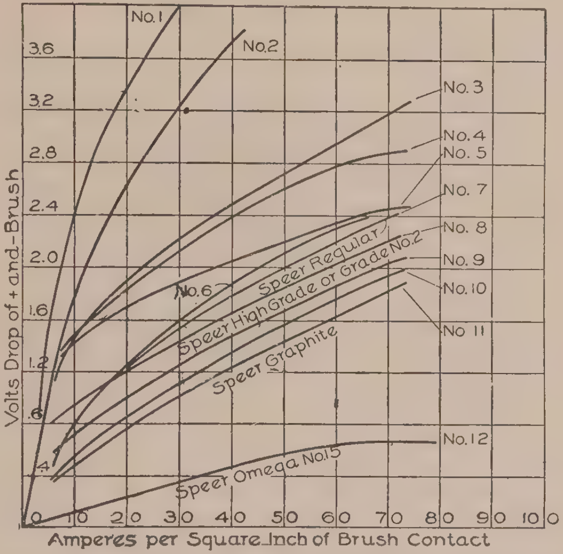


Fig. 68. Voltage-Drop Curves of Various Grades of Carbon and Graphite Brushes at Different Current-Densities.

(5) Keep the surface of the commutator smooth.

(6) Add special features to the machine.

To see clearly the application of most of these special features, it is desirable that we first consider another property of an armature carrying current—namely, its demagnetizing effect.

Demagnetizing Effect of Armature. To eliminate sparking at the commutator, we have seen that it is necessary to shift the brushes ahead of the neutral line in generators, and back in case of motors. The resultant effect is to produce in the armature a magnetomotive force (m. m. f.) opposed to that of the field-winding. Considering Fig. 69, wherein the brushes are supposed to be shifted to the line *nn′*, the remainder of the figure being as before, it is seen that the currents are flowing toward the observer in the armature conductors to the left of the neutral line *nn′*, and from the observer in those to the right of that line. Now, suppose the two vertical lines *ad* and *bc* to be drawn across the section of the armature and through the points of commutation. The armature conductors are thus divided into two bands, those to the right of the line *ad* and to the left of the line *bc* tending to cross-magnetize the armature, while those included between these lines produce a m. m. f. opposed to that of the main field, since the current in these turns passes around the flux in a direction opposed to that of the field-exciting current. The breadth of the belt of demagnetizing windings is evidently proportional to the angle of lead, since it subtends double that angle. In such an armature generating 50 amperes, each conductor would carry 25 amperes, since there are two paths in parallel; and as the number of cross-magnetizing turns is 12, and the number of demagnetizing turns is 4, the "cross-ampere-turns" would be $25 \times 12 = 300$; and the number of "back ampere-turns" would be $25 \times 4 = 100$.

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* With respect to material and thickness, see Fig. 68.

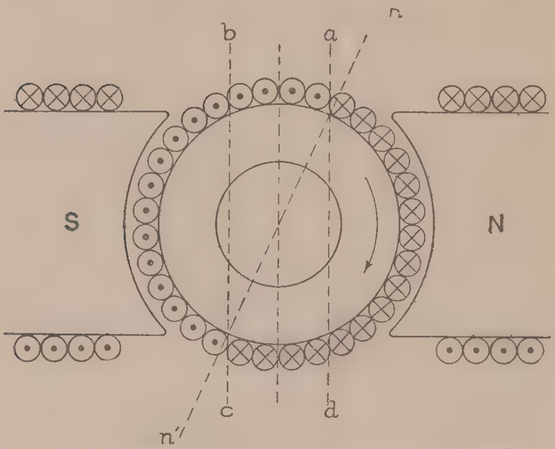

Fig. 69. Demagnetizing Action of Armature Current of Generator.

This demagnetizing influence, which is proportional to the angle of lead of the brushes, tends to weaken the field in general, while the cross-magnetization, proportional to the ampere-turns not included in the demagnetizing effect, tends to weaken the flux under the hindward pole-horn, and strengthen that under the forward pole-tip. Hence the impressed m. m. f. (that of the field-magnets) must be strong enough to force through the air-gap in the magnetic circuit sufficient flux to permit of sparkless commutation in spite of the demagnetizing effects. Since the cross-magnetization is responsible for the distortion which produces sparking, it remains to consider the remedies.

Cross-Reluctance Remedies. Fig. 70 shows that increased air-gap in the magnetic circuit *HAGDH* will diminish the cross-flux. This method is somewhat objectionable, however, because, in order to produce the same flux through the field-circuit, a greater m. m. f., and hence a larger number of field-exciting turns, are required. This disadvantage may be overcome in some types of generators by forming a V-groove in the polar mass behind the face, as shown in Fig. 71.

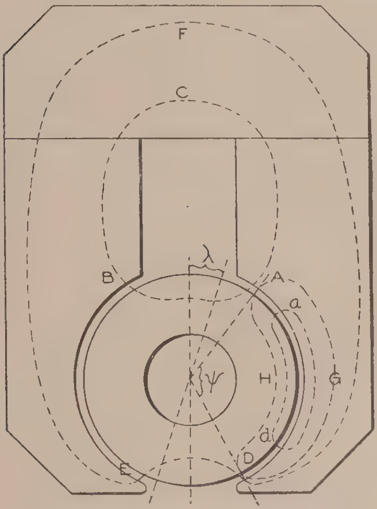

Fig. 70. Armature Interference.

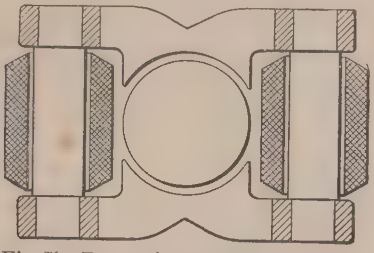

Fig. 71. Prevention of Cross-Reluctance by V-Groove in Back of Polar Mass.

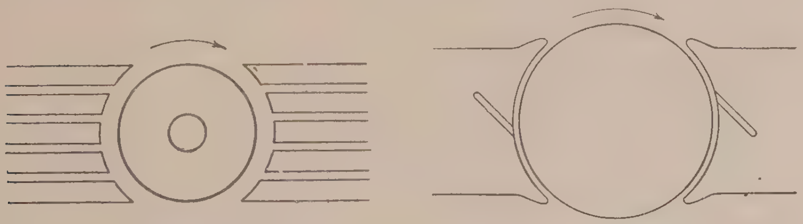

Fig. 72.

Fig. 73.

Remedies for Cross-Reluctance.—Pole-Pieces Made with Longitudinal Gaps or Oblique Slots.

Another plan is to thin down or actually separate the two halves of the circuit, and thus throttle the cross-flux. S. P. Thompson has suggested constructing the field-cores of pieces of iron with longitudinal gaps, as indicated in Fig. 72, or slotting the pole-piece obliquely as in Fig. 73, the neck of the casting here becoming highly saturated and offering large reluctance to the cross-field.

Another arrangement consists in making the forward horn of cast iron, and the rearward horn of cast steel, the joint being oblique, as indicated in Fig. 74.

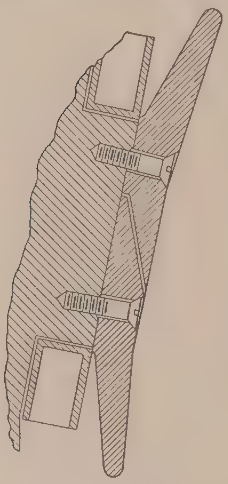

Fig. 74. Composite Pole-Shoe, Forward Horn Cast Iron; Hindward, Cast Steel, Meeting Obliquely to Minimize Magnetic Distortion at Full Load.

Cross-Compounding Remedies. Some designers provide a m. m. f. equal but opposed to the cross-magnetic m. m. f. Elihu Thomson placed a series ("compounding") coil on a separate frame surrounding the armature, and tilted it in a direction counter to the rotation so as partially to counteract the cross-flux. Swinburne suggested that a small auxiliary coil in series with the armature be wound around the pole-tip in order to maintain a field for reversal at this point (Fig. 75, *a*).

Menges, Mather, Swinburne, and others have advocated the use of auxiliary poles at right angles to the main poles, excited by coils in series with the armature. This feature is now embodied in the *Inter-pole* motor. S. P. Thompson proposed the use of compound winding having series and shunt coils at different angles, so that, as the armature reaction tended to shift the main flux forward, the increased current in the series coils would produce a m. m. f. tending to drive it back. Menges suggested winding series turns upon the polar parts of machines with double magnetic circuits. He was the first to suggest (1884) a cross-compound winding having the auxiliary poles set to produce a flux at right angles to the main flux.

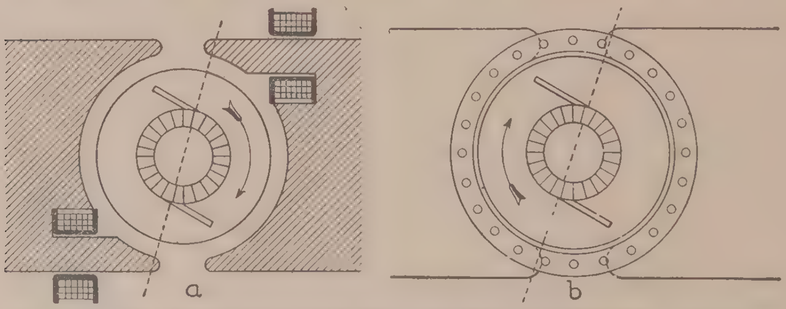

Fig. 75. Devices for Sparkless Collection of Current—(*a*) Swinburne; (*b*) Hutin and Leblanc.

Fisher-Hinnen, Professor Forbes, Mordey, and S. P. Thompson wind these coils in a notch at the center of the pole-face. Elihu Thomson also suggested the use of *unwound* auxiliary poles at right angles to the main poles, thereby leading off the cross-flux to strengthen the main flux.

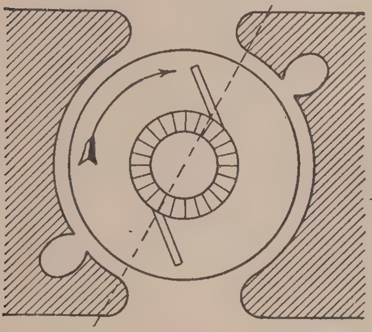

Fig. 76. Sayers' Device for Sparkless Collection of Current.

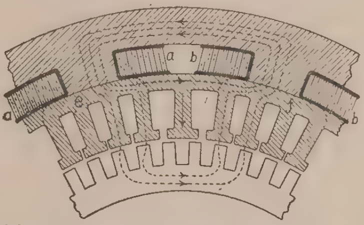

Fig. 77. Ryan's Compensating Devices.

The most complete solution was proposed independently by Professor Ryan and Fisher-Hinnen, who insert a number of coils

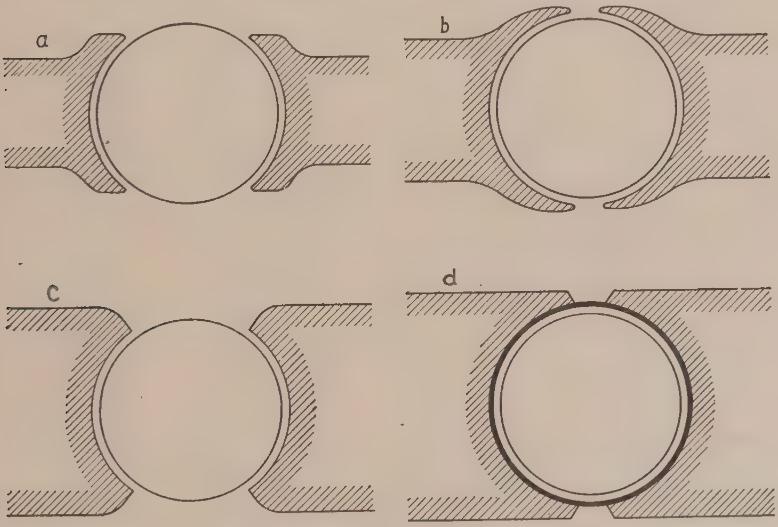

Fig. 78. Various Forms of Pole-Tips.

in slots cut in the face of the pole parallel to the shaft, the coils being connected in series with the external circuit, and constituting a stationary winding which produces a m. m. f. equal but opposed to that due to the armature, Fig. 77. This device is not extensively employed, however, on account of the increased heating as well as complication and cost.

Hutin and Leblanc proposed the placing of rods of copper in the pole-face, which rods are short-circuited upon themselves. This arrangement is intended to prevent oscillations in the direction of the magnetic flux at commutation. It is much used in alternating-current machines, to facilitate parallel operation (see Fig. 75, *b*).

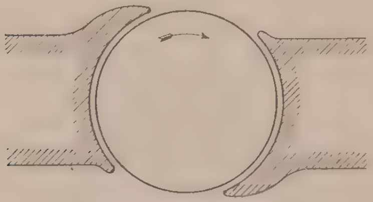

Fig. 79. Unsymmetrical Pole-Pieces Designed to Concentrate Field.

Concentration of Field. Sparkless commutation may also be accomplished if the field is magnetically rigid—that is, not easily distorted. This stiffness may be partially secured by properly shaping the pole-faces or by making notches in them (Fig. 76), as suggested by Sayers, thus concentrating the flux at the tip. In Fig. 78 are shown various forms of pole-tips, of which type *a* is not always good, but may be either extended as in *b*, or cut off as in *c*. An extreme arrangement, suggested by Dobrowolsky, surrounds the armature completely with iron, as in *d*.

Another scheme, proposed by M. Gravier, employed the unsymmetrical form of poles shown in Fig. 79. When the machine is working at small loads, the flux in the gap is nearly uniform; but at large loads, the distortion due to armature current forces the flux forward and saturates the forward pole-horn, thus preventing much change in its flux-density, on account of the saturation and the diminished area. Lundell combines this device with the slotted-pole method, and produces the pole shown in Fig. 80. Another plan is to make the pole-cores of laminated wrought iron or steel, to which a cast-iron pole-piece is attached.

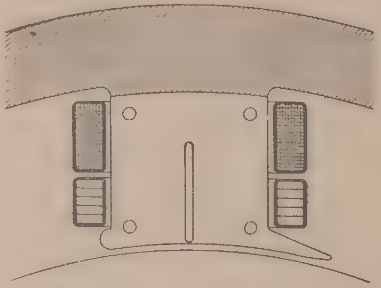

Fig. 80. Lundell's Form of Pole.

A similar effect is produced by making the poles non-concentric with the armature, as in Fig. 81. This secures a suitable fringe and at the same time maintains a fair magnetic rigidity. Mr. C. E. L. Brown finds that inwardly projecting poles of circular cross-section, without any pole-shoes or extensions, produce excellent results in generators which deliver large current. Other devices for securing a gradual entrance of the armature conductors into the field, are to skew the hindward edge of the pole-shoe as indicated in Fig. 82; to shape the pole-shoes with polygonal ends, Fig. 83; or to provide clawed edges, Fig. 84. Some manufacturers leave out every other lamina in the pole-tips, the resulting extra saturation helping to resist the effects of armature distortion. A somewhat similar device is that patented by Marshall, which consists in attaching to the pole-piece groups of short, laminated iron plates with narrow spaces between them, thus reducing the net area of the shoe, while preserving the same effective area.

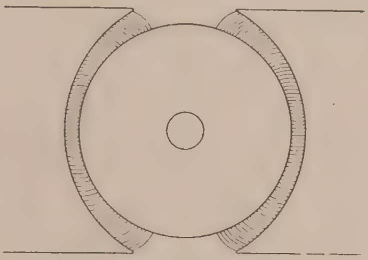
Fig. 81. Non-Concentric Poles.

Self-Compensating Armatures. The devices of Swinburne and Mordey, which relate to chord winding, have met with considerable success. The most prominent of these methods is that of Sayers, who connects the commutator-bars to the armature winding through auxiliary compensating coils. One end of each commutator coil, Fig. 85, is attached to the junction between two main armature coils, and the other end is connected to a commutator segment. The armature and commutator coils are represented while short-circuited by the brush, a rapid reversal of current being produced by the commutator coil and auxiliary pole. With this method of winding, the

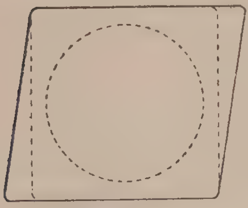
Fig. 82.

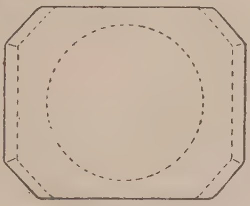
Fig. 83.

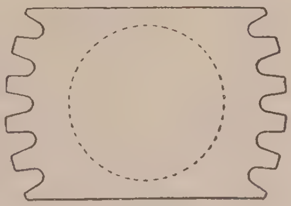
Fig. 84.

Devices for Securing Gradual Entrance of Armature Conductors into Field.

brushes may be given a backward lead, thus making the generator self-compounding without a series field-coil.

This completes the list of special features that may be added to generators or motors to eliminate sparking at the commutator; but most of these methods are not likely to be employed, on account of increased complications and reduced efficiency. In the largest machines built by the best manufacturers, none of these special features are present, because it is found that the heating limit of the machine is usually reached before sparking occurs. One prominent designer pays no attention to armature reaction, but relies upon a large number of commutator segments to keep the e. m. f. per segment at a very low figure, also minimizing the self-inductance of each armature coil by making it of few turns and of short length parallel to the shaft. For medium sizes or high-speed work, this design is now much used, especially where large distorting effects are present.

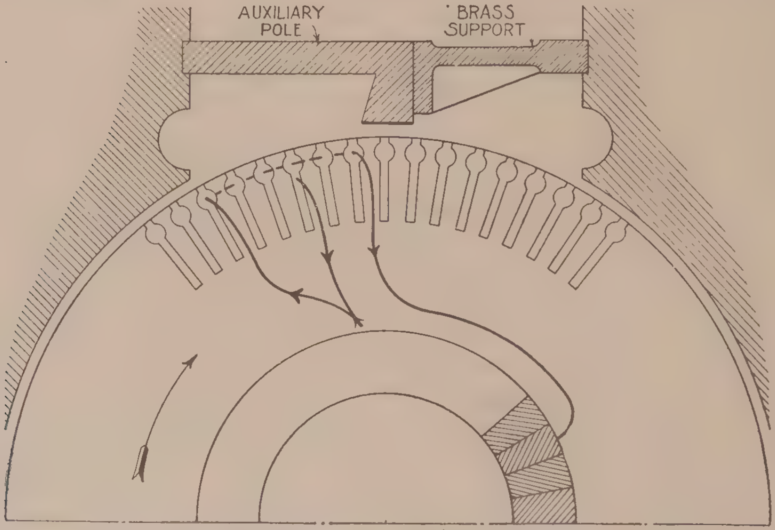

Fig. 85. Sayers Compensating Winding, with Commutation Coils.

Conclusions. The special points to be observed in order to prevent sparking at the commutator may therefore be stated as follows:

1. The armature ampere-turns per pole should not exceed certain definite values in machines of a given type. If the volts per commutator segment are 5 or less, the armature ampere-conductors should not exceed

20,000 per pole; while with 10 volts per segment, the ampere-conductors should not exceed 10,000.

2. Long air-gaps are unnecessary if the armature teeth are highly saturated—that is, have a flux-density of from 20,000 to 23,000 apparent lines* per square centimeter, or 125,000 to 150,000 apparent lines per square inch, both of the injurious effects of armature reaction being diminished.

3. Armatures should be as short as possible in order to reduce the self-inductance of the armature coils.

4. Number of volts per commutator segment should be low.

5. Inductance of the short-circuited coils should be low compared with brush-contact resistance, and the current-density in carbon brushes should be about 35 amperes per square inch.

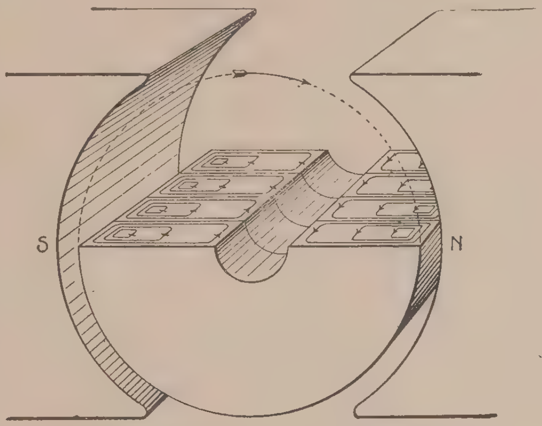

Fig. 86. Eddy Currents in Core-Discs.

Dead Turns. On account of the various internal reactions present in the armature, the terminal voltage is not quite proportional to the speed with constant field-current. Inasmuch as the machine acts as though some of its speed were ineffective, the name *dead turns* has been given to those revolutions by which the actual speed at any output exceeds that determined by strict proportionality.

Spurious Resistance. There is present in every rotating armature an apparent resistance proportional to the speed, due to the self-induction of the armature, as first pointed out by Cabanellas. It cannot be reduced by dividing the armature conductors into a greater number of segments, but can be made less by decreasing the number of conductors and increasing the cross-section of iron in the magnetic circuit. Its value is lessened by the introduction of a counter-e. m. f. aiding the commutation of the current, as previously explained.

Eddy Currents. In discussing the magnetic circuit, it was shown that parasitic currents may be produced in the iron parts of generators if any of these parts form closed electrical circuits and cut flux. In the armature, the iron core rotates in a magnetic field; eddy currents are set up in this core, as shown in Fig. 86, and unless prevented from flowing, these currents will lower the efficiency of the machine. Eddy currents will also be produced in the pole-faces, due to the variation of the magnetic flux, as shown in Figs. 87–92; and they may in addition manifest themselves in the armature conductors if the latter are large.

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* By *apparent lines per square centimeter in the teeth* is meant the flux-density which would be present in the teeth if all the flux issuing from the poles entered the armature core through the teeth.

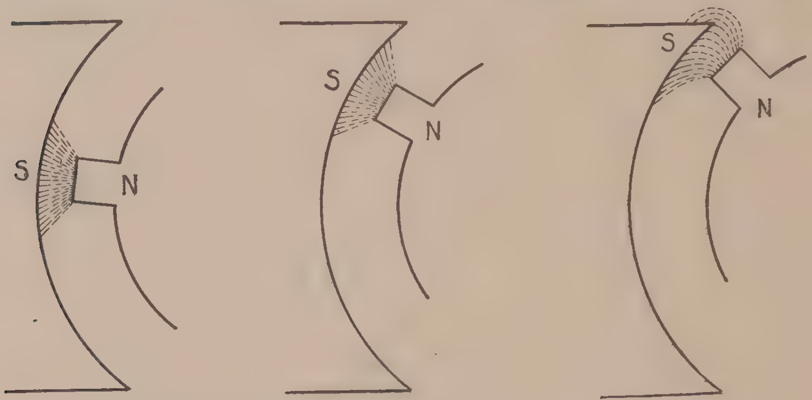


Fig. 87. Fig. 88. Fig. 89.

Alteration of Magnetic Field Due to Movement of Mass of Iron in Armature.

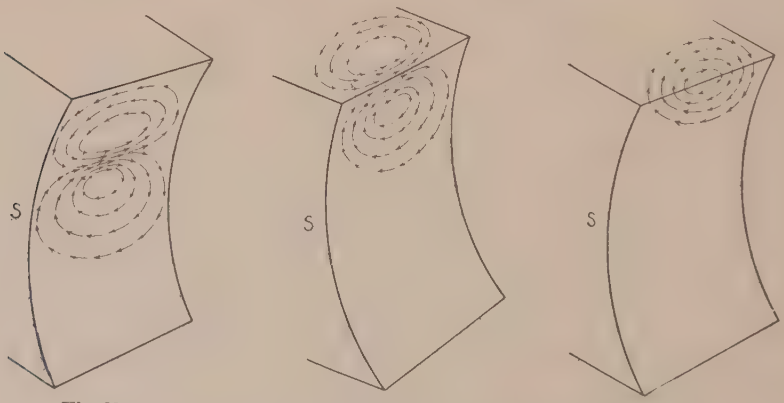


Fig. 90. Fig. 91. Fig. 92.

Eddy Currents Induced in Pole-Pieces by Movement of Masses of Iron.

In all cases where eddy currents are likely to be large, the circuits affected are laminated so that the plane of lamination cuts across the path of this parasitic current.

Drag on Armature Conductors. A conductor carrying a current is surrounded by a magnetic field, as shown on page 2. If, now, such a conductor be placed in a uniform magnetic field—as, for example, between a large north pole and a large south pole—a compound field will result, having the distorted appearance shown in Fig. 93. The direction of the mechanical force exerted may be determined by supposing that the flux acts as a bundle of elastic cords tending to shorten themselves. As a matter of fact, there is tension in the direction of the flux, and stress at right angles to it, proportional at every point to the square of the flux-density. A conductor in which current is supposed to be flowing toward the observer will therefore be urged in the direction of the arrow, Fig. 93; so that in every dynamo-electric machine the current generated produces a mechanical reaction which tends to stop the motion producing them.

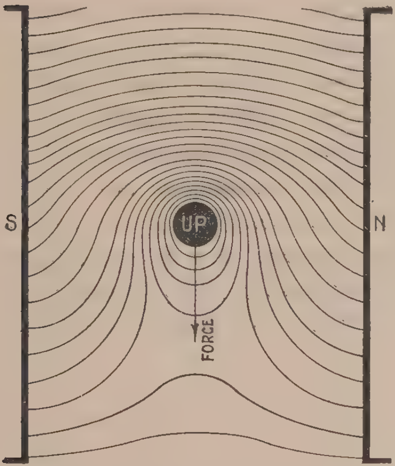


Fig. 93. Magnetic Lines Due to Conductor Carrying Current Placed in Magnetic Field.

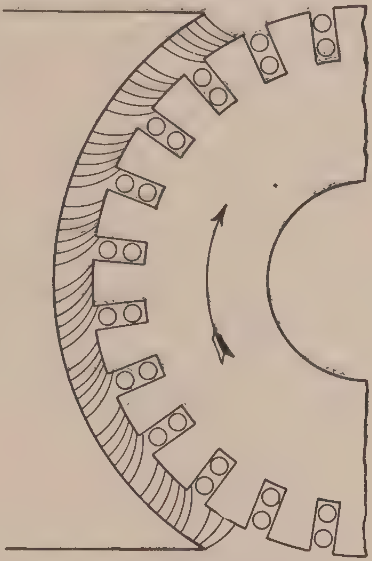


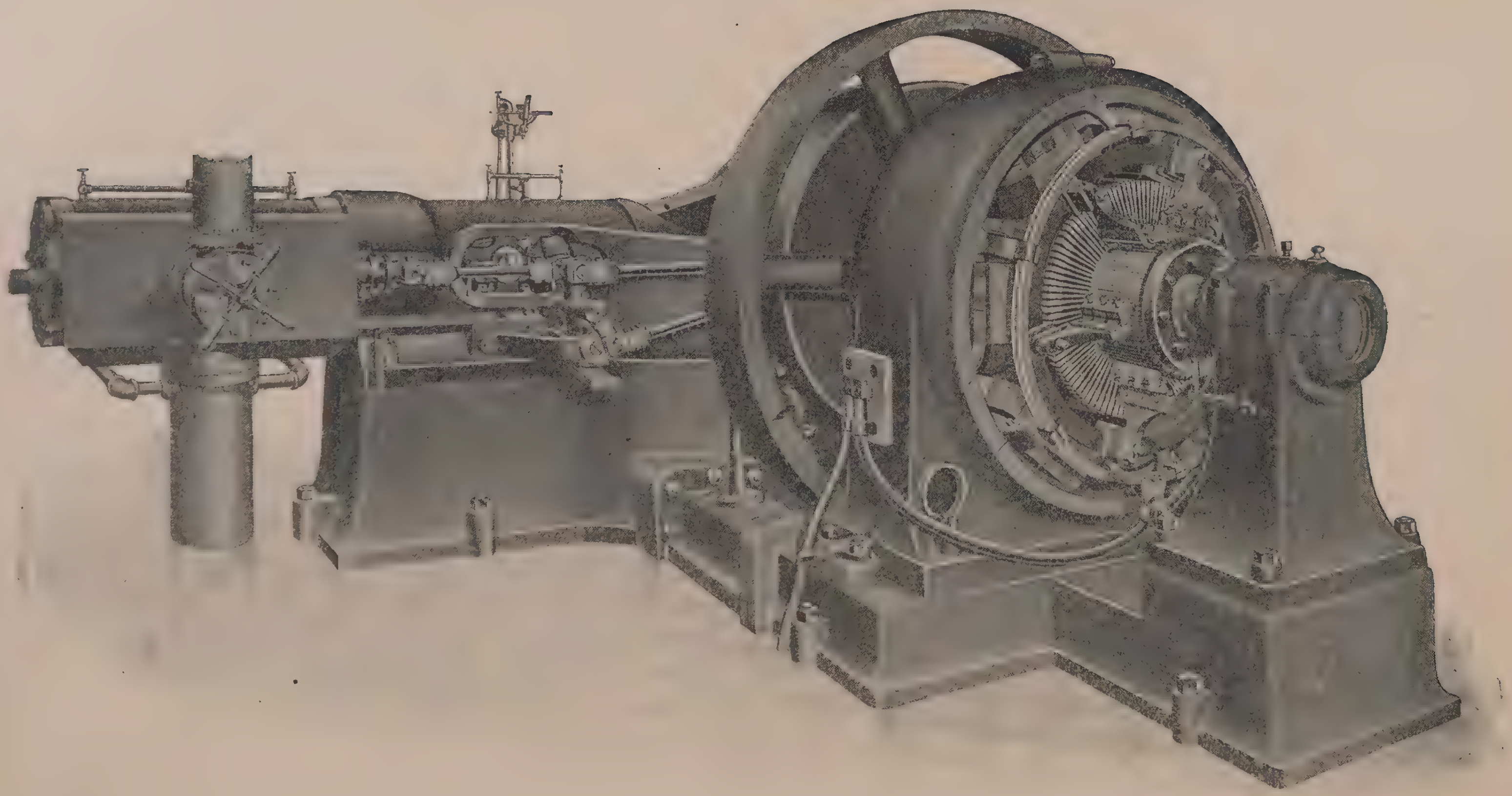
Fig. 94. Magnetic Field of Slotted Armature.

If the conductors are imbedded in slots or holes in the armature core, Fig. 94, it is found that the drag comes upon the iron, the magnetic field being distorted as shown. In fact, the flux no longer directly cuts the conductors, but, as it were, flashes from tooth to tooth. In addition to thus relieving the conductors of the drag effect, the teeth permit a much smaller air-gap to be used, sometimes reducing it to a mere mechanical clearance.

Stray=Power. In all practical machines there is a difference between the input and the output. In electrical machines, this discrepancy is caused by the following reactions:

1. Armature-resistance drop producing I^2R effects.
2. Friction of bearings and brushes.
3. Air-friction of the rotating armature.
4. Hysteresis in the armature core.
5. Eddy currents in the armature core, conductors, and polar projections.
6. Energy is also consumed in the field winding, due to I^2R effects.

Nos. 2, 3, 4, and 5 are grouped under the head of *stray power losses*, being from 40 to 60 per cent of the total loss. No. 3 is small, except in those cases where the armature spider is provided with fans to aid ventilation, and where special ventilating ducts are provided in the armature, as in most modern machines. No. 4 is by no means negligible, but never adds more than 1 per cent to the driving power. No. 5 is the most important of all, especially in large machines. It makes its presence felt even in the metal of the shaft, and there will be power wasted if flux leaks through this portion.



HEAVY DUTY, SIMPLE ENGINE DIRECT CONNECTED TO D. C. GENERATOR.
Buckeye Engine Company

DYNAMO-ELECTRIC MACHINERY

PART II

CALCULATIONS AND CHARACTERISTIC CURVES OF CONTINUOUS-CURRENT GENERATORS

Symbols. The symbols used in the discussions now to be taken up, are as follows:

b — Number of external wires in a section of the armature.
c — Number of circuits in parallel through an armature.
E — Entire e. m. f. generated in an armature, in volts.
e — Lost volts, or potential drop in volts, of armature.
η — Commercial efficiency.
η_1 — Economic coefficient, or electrical efficiency.
η_2 — Gross efficiency, or efficiency of conversion.
F — Force—*i.e.*, push or pull—in pounds' weight.
ϕ — Flux per pole.
I — Current in external circuit, in amperes.
I_a — Current in armature circuit, in amperes.
I_{sh} — Current in shunt field-exciting coil, in amperes.
I_{se} — Current in series field-exciting coil, in amperes.
K — Number of commutator segments.
L — Coefficient of self-induction, or inductance, in henrys
λ — Angle of lead of brushes.
M — Volts per revolution per second.
μ — Magnetic permeabilty.
n — Revolutions per second.
ν — Coefficient of magnetic dispersion, or leakage coefficient
p — Number of poles.
q — Ampere conductors per inch of periphery of curvature.
R — Resistance of external circuit, in ohms.
r — Total internal resistance of generator, in ohms.
r_a — Total resistance of armature *coils*, in ohms.
r_{sh} — Resistance of shunt field-exciting coils, in ohms.
r_{se} — Resistance of series field-exciting coils, in ohms.
r.p.m. — Revolutions per minute.
ψ — Angle of pole span.
σ — Space-factor.
T — Number of turns.

T_{sh} — Number of field-exciting turns in shunt with armature.
T_{se} — Number of field-exciting turns in series with armature.
t — Time in seconds.
V — Volts at terminal of a generator.
v — Velocity in feet per second.
W — Power in watts.
ω — Angular velocity in radians per second.
y — Winding pitch.
y_f — Forward winding pitch.
y_b — Backward winding pitch.
Z — Number of conductors on the armature, counting all around periphery.

Fundamental Equation. We have seen on page 17 that an e. m. f. of one volt is generated when 10^8 lines are cut per *second*. Now, as most armatures have more than one conductor cutting the field flux, the e. m. f. generated will be a direct function of the number of conductors connected in series.

Assuming that the sections of the armature winding equal in number the commutator bars (K), the external conductors all around the armature will be bK. The total number of conductors that are in series with each other electrically from brush to brush is $\frac{bK}{c}$ or $\frac{Z}{c}$. If, now, the armature speed of rotation is given in r. p. m., then the revolutions per second $(n) = \frac{\text{r. p. m.}}{60}$.

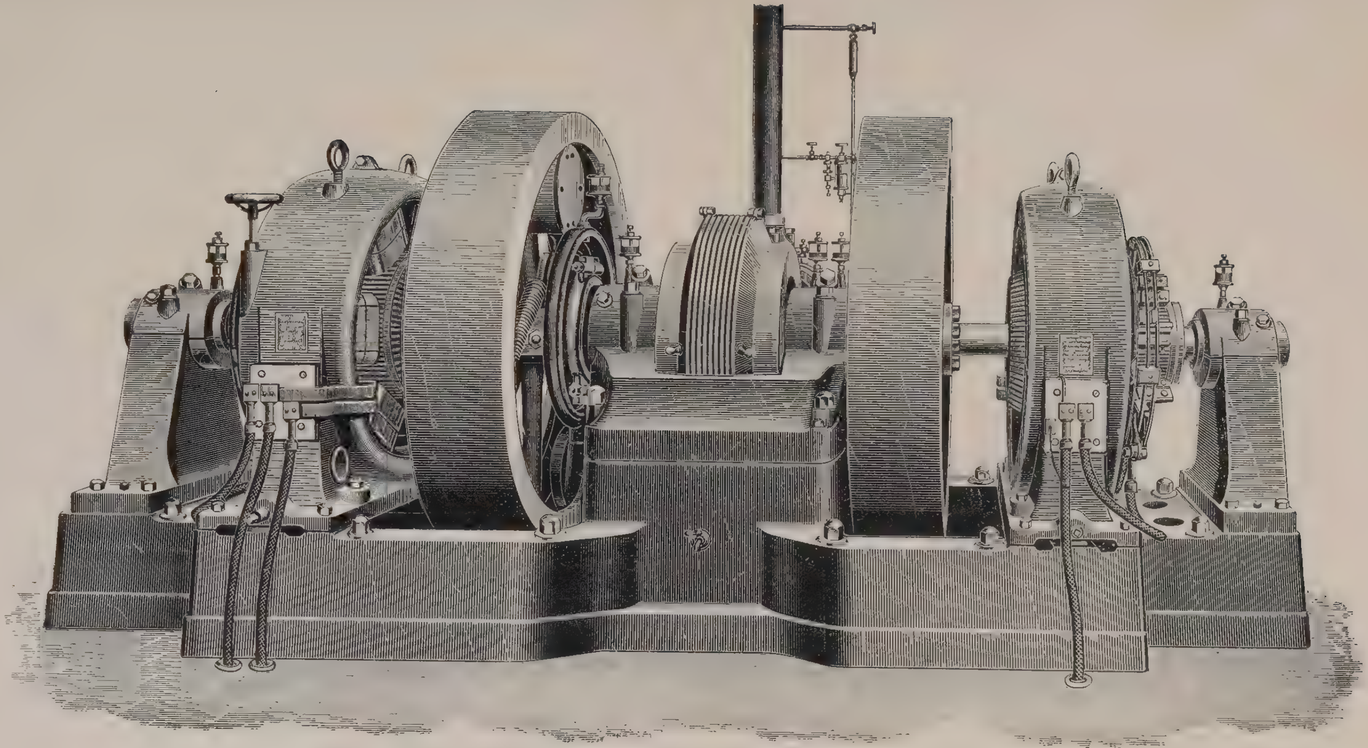
In order to compute the e. m. f. generated, we have:

Number of lines cut by one external wire in one revolution .... $= p\phi$
Number of lines cut by 1 external wire in 1 second .... $= np\phi$
Number of lines cut by $\frac{Z}{c}$ external wires in series in 1 second .... $= np\phi Z \div c$
Average e. m. f. generated, in C.G.S. units .... $= nZ\phi\frac{p}{c}$
Average e. m. f. generated, in volts .... $= \frac{nZ\phi}{10^8}\,\frac{p}{c}$
Average e. m. f. generated, in volts .... $= \frac{\text{r. p. m.} \times Z\phi p}{60 \times 10^8 \times c}$ **(1)**

If the number of circuits through the armature is equal to the number of poles in the field, we may write:

$$\text{(Average) } E = \frac{\text{r. p. m.} \times Z\phi}{10^8 \times 60} = Mn \qquad \textbf{(2)}$$

It must be remembered that this e. m. f. is an average, and that it



ENGINE DIRECT-CONNECTED WITH TWO WESTINGHOUSE GENERATORS.

Ames Iron Works.

depends upon the construction of the armature how much fluctuation takes place during a rotation, as shown on page 22.

Example. Assume a 4-pole machine with a 4-circuit armature winding; the flux per pole, 2,000,000 lines of force; the total number of inductors in the armature, 600; and the speed of the machine, 1,200 r. p. m. Determine the generated voltage.

Substituting in Equation 1, we have;

$$E = \frac{1{,}200 \times 600 \times 2{,}000{,}000 \times 4}{60 \times 10^8 \times 4} = 240 \text{ volts.}$$

Efficiency of a Generator. The efficiency of a generator is defined to be the ratio of the mechanical power applied to the rotation of the armature of the generator at any given load, to the electric power output at that load. The mechanical power expended in turning the armature against the resisting forces may be measured mechanically by a dynamometer, or by taking indicator cards at the engine and allowing for friction. By far the best method is the electrical one, of using an electric motor, which has been carefully calibrated, to determine the mechanical power required to operate the generator at any given load. The Hopkinson or so-called *pumping-back* arrangements are even more commonly adopted, especially for large units.

The electrical power is expressed as the product of amperes of current and volts difference of potential between the two terminals of that part of the circuit in which the energy is being expended. This product, measured by suitable instruments, expresses the power or energy expended per second in the circuit in watts, the electrical unit of power. The mechanical unit of power (that is, the horse-power, h. p.), is practically equal to 746 watts*. We may therefore write,

$$\text{h.p.} = \frac{W}{746} = \frac{I \times V}{746} \quad \text{.............................} \quad (3)$$

The electrical efficiency or economic coefficient of a generator is defined to be the ratio between the electrical power utilized in the external electrical circuit and the electrical power developed in the armature. So that if, through an armature there are flowing I_a amperes due to a generated e. m. f. (E), the electrical activity expressed in watts will be EI_a.

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* 1 h. p. = 745.560 watts exactly (Henry's *Conversion Tables*).

If the voltage at the terminals of the generator be V volts, and the current through the external circuit be I amperes, the useful power in watts will be $V \times I$.

Therefore the *economic coefficient* of the machine will be:

$$\eta_1 = \frac{\text{Useful electrical power}}{\text{Total electrical power}} = \frac{V \times I}{E \times I_a}.$$

The efficiency of electric conversion is defined as the ratio of the power developed in the armature to the mechanical power expended in producing it. This may be written:

$$\eta_2 = \frac{EI_a}{746 \times \text{h. p.}}.$$

Hence the commercial or true efficiency of the generator becomes:

$$\eta = \eta_1 \times \eta_2 = \frac{VI}{746 \times \text{h. p.}}.$$

It may also be obtained by taking the ratio between the output in watts, and the sum of the output and losses in watts; that is,

$$\eta = \frac{VI}{VI + \Sigma W'};$$

in which $\Sigma W'$ represents the sum of the mechanical and electrical losses in the generator. By multiplying the right-hand member of this last equation by 100, the commercial efficiency is obtained as a percentage.

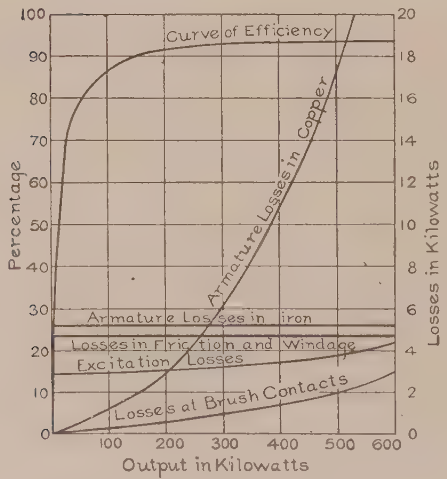

Fig. 95. Typical Curve of Efficiency.

The efficiency of a generator is by no means constant throughout all ranges of loading. On the contrary, because of the variation of the generator losses with the current through the armature, the efficiency curve takes some such form as that shown in Fig. 95. Here it is seen that the efficiency increases very rapidly from 0 to about 80 per cent at 80 kilowatts output, beyond which it increases slowly until it reaches a maximum value at about 550 kw. From this point it decreases slowly; and with still further increase in load, the efficiency would continue to decrease, but more and more rapidly. This is made clear when the curves representing the variation of the losses with load are examined. Assuming speed and voltage constant, it is seen that the friction, windage, and iron losses increase very slowly with output. The copper losses in the armature and field, and the brush-contact losses, increase, however, as the square of the current, and thus at large overloads attain enormous proportions. By proper design, the efficiency curve may be made to take any desired form within certain limits, the maximum point being usually designed to occur at the normal load.

Magneto Generator. In this type of dynamo the flux through the armature is due to the permanent field magnets. Thus ϕ depends both upon their magnetic strength and upon the cross-section of iron core of the armature and the air-gaps. If the current drawn from the machine is sufficiently great, the reaction of the armature will diminish ϕ, and lessen the generated e. m. f. (assuming constant speed of rotation). If, however, the current drawn produces a negligible effect upon the flux through the armature, the voltage of any given magneto machine will be directly proportional to the speed of rotation, by Equation 1, page 62.

The voltage at the terminals of the magneto as well as other types of electric generators, is not equal to that generated in the armature conductors. The armature winding is always of appreciable resistance, so that the passage of any current through it produces a drop of potential, in addition to which there is also a drop due to the brush-contact resistance. It is convenient to have an expression for E in terms of the terminal voltage V and other measurable quantities, because E cannot be measured directly when any current is being drawn.

Let r be the total internal resistance of the armature of the generator, measured at the brushes; let R be the total external resistance; and let I be the current. Then by Ohm's law,

$$E = I(R + r) \quad \text{......................} \quad (4)$$

$$e = Ir$$

$$V = IR;$$

so that,

$$\frac{V}{E} = \frac{R}{R + r} \quad \text{......................} \quad (5)$$

and

$$E = V + Ir = V + e \quad \text{..................} \quad (6)$$

which means that the generated e. m. f. is equal to the sum of the terminal voltage and the armature-resistance drop. This latter increases directly with the armature current, but in well-designed machines is arranged so as not to exceed 2 or 3 per cent at rated load.

On page 64 the economic coefficient was shown to be

$$\eta_1 = \frac{V\,I}{E\,I_a}.$$

In the magneto machine, $I = I_a$; so that, from Equation 5,

$$\eta_1 = \frac{V}{E} = \frac{R}{r+R} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

This equation shows that as the resistance of the armature is decreased, the economic coefficient of the machine increases, the *theoretical* maximum of unity being attained when the armature resistance is *nil.* This is true for all electrical machines.

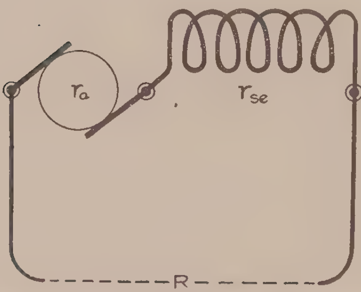

Fig. 96. Diagrammatic Representation of Series Generator.

Separately-Excited Generator. For this type of dynamo the same formulæ hold as for magneto generators. In this case, however, the flux per pole ϕ depends upon the strength of the field-exciting current secured from an independent source. In estimating the commercial efficiency, this fact must be taken into account, the power thus spent being usually from 1 to 3 per cent of the output of the machine, the larger figure relating to the smaller machines.

Series Generator. The series generator, shown diagrammatically in Fig. 96, has but one circuit and one current (I), whose strength depends upon the generated e. m. f. (E) and the total resistance in the circuit. Using the notation previously adopted, we have by Ohm's law:

$E = I\,(R + r_a + r_{se})$; and $V = IR$. Hence

$$V = E - (r_a + r_{se})\,I.$$

The economic coefficient will be:

$$\eta_1 = \frac{\text{Useful power}}{\text{Total power}} = \frac{I^2\,R}{I^2\,(R + r_a + r_{se})} = \frac{R}{(R + r^a + r_{se})} = \frac{V}{E} \quad \ldots\ldots (8)$$

This is obviously highest when r_a and r_{se} are *both* very small. They are usually about equal.

Shunt Generator. In the shunt dynamo, Fig. 97, the field and the external circuits are in parallel, so that we have two circuits to consider.

Let I = the current in the external circuit;
I_a = the current in the armature;
I_{sh} = the current in the shunt field-circuit.

Then,

$$I_a = I + I_{sh};$$

for it is clear that the current produced in the armature divides between these two parts of the circuit only.

Calling that part of the armature current which passes through the shunt winding and is consequently not available in the external circuit, the *lost amperes** = I_{sh}, we have the resistance of the shunt coils,

$$r_{sh} = \frac{V}{I_{sh}}.$$

In modern machines, r_{sh} is so proportioned that the shunt field amperes constitute from 1 to 3 per cent of the whole current output of the machine, the larger value being for the smaller generators.

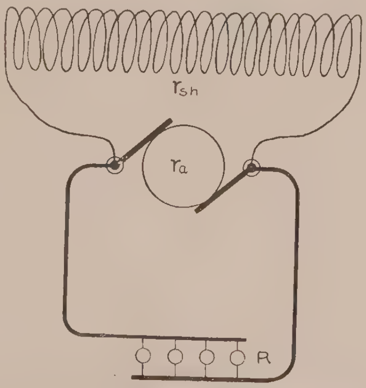

Fig. 97. Shunt Dynamo Showing Main and Shunt Circuits.

Example: In a standard Crocker-Wheeler 85 kw. shunt generator, 3.3 amperes was required in the field-exciting circuit, the generator giving 370 external amperes at 230 volts. Thus the resistance of the field winding was 69.7 ohms, the armature current was 373 amperes, and the shunt field current was about 1 per cent of the rated load current.

We may now compute the economic coefficient of a shunt-wound generator as follows:

The total watts produced in the armature of the machine are:

$$W = E I_a \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

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*S. P. Thompson's *Dynamo-Electric Machinery*, N. Y., 1904, Vol. I, Page 300.

and the watts delivered to the external circuit are

$$w = V\,I \qquad (10)$$

We also have

$$E = V + I_a\,r_a = V + (I + I_{sh})\,r_a\,, \qquad (11)$$

since

$$I_a = I + I_{sh}$$

Substituting these values in Equation 9, we obtain:

$$\begin{aligned} W &= (V + Ir_a + I_{sh}\,r_a)\,(I + I_{sh}) \\ &= VI + VI_{sh} + (I + I_{sh})^2\,r_a \\ &= VI + VI_{sh} + I_a^2\,r_a \qquad (12) \end{aligned}$$

which reads: The watts produced in the armature are equal to the sum of the watts delivered to the external circuit, the watts wasted in the shunt field, and the watts dissipated in heating the armature conductors. Considering, then, the purely electrical efficiency of a shunt-wound generator, the iron losses, friction, windage, and other mechanically supplied losses not being present in Equation 12, we have,

$$\eta_1 = \frac{w}{W} = \frac{VI}{VI + VI_{sh} + I_a^2\,r_a} \qquad (13)$$

In order that this ratio may approach unity, its limit, the sum of the losses must approach zero. Writing the latter as a fraction of the output, we have,

$$\begin{aligned} \frac{1 - \eta_1}{\eta_1} &= \frac{V\,I_{sh} + I_a^2\,r}{VI} \\ &= \frac{I_{sh}}{I} + \frac{I_a\,r_a}{V} \qquad (14) \end{aligned}$$

which shows that the two terms are of equal importance, assuming that $I_a = I$, *i.e.*, that the shunt-exciting current is negligible, as in practice it rarely exceeds 2 to 3 per cent of the rated current.

Equating these two terms, and inserting for I_{sh} its value $V \div r_{sh}$, there is obtained,

$$\frac{I\,r_a}{V} = \frac{V}{I\,r_{sh}} \qquad (15)$$

that is

$$\frac{V}{I} = \sqrt{r_a\,r_{sh}} = R \qquad (16)$$

showing that the external resistance is a geometric mean between the armature resistance and the resistance of the shunt-field winding.

Substituting in Equation 14, for I and V, their values in terms of resistances as given above, we have,

$$\frac{1-\eta_1}{\eta_1}=\frac{R}{r_{sh}}+\frac{r_a}{R} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (17)$$

from which it is obvious, that for the percentage of losses to be small, the shunt-winding resistance must be large in comparison with the armature resistance.

It must be clearly borne in mind throughout the preceding discussions, that the *commercial efficiency* is always lower than the so-called "electrical efficiency," since the latter does not include the mechanically supplied losses due to friction, windage, hysteresis, and eddy currents. The economic coefficient, or electrical efficiency, may be used to compare various types and to show the conditions for best electrical working; but the commercial efficiency is the true and final test for any given machine.

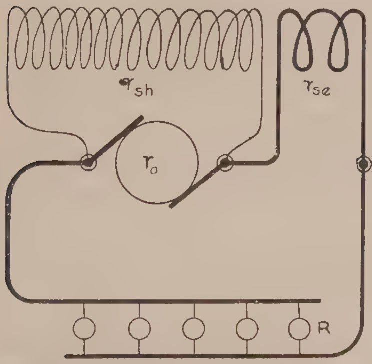

Fig. 98. Short-Shunt Method of Connecting Shunt-Coils to Dynamo.

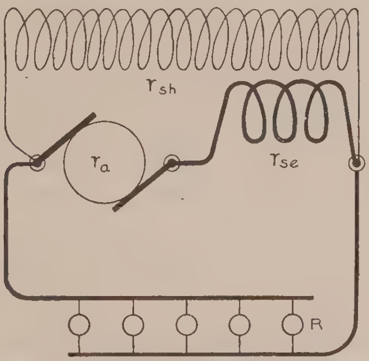

Fig. 99. Long-Shunt Method of Connecting Shunt-Coils to Dynamo.

Compound-Wound Generator. Under this head will be considered that type of compound dynamo in almost universal use at the present time. This may be regarded as either a shunt machine in which series turns have been added to the field winding in order to compensate for the drops due to armature resistance and armature reactions; or as a series generator to which shunt windings have been added in order to produce an initial magnetization. In either case, there are two possible ways of connecting the terminals of the shunt coils to the source of voltage, known respectively as the *short-shunt* and *long-shunt* methods.

In the short-shunt method, the shunt coils are connected directly across the brushes of the machine, Fig. 98; while in the long-shunt arrangement, Fig. 99, the shunt coils may be considered as a shunt to the external circuit. In the former method the voltage applied to the terminals of the shunt windings is not a constant, but increases with load if the generator be assumed to be compounded to give a constant or increasing terminal voltage with load. In the long-shunt method, the voltage at the terminals of the shunt coils will be the same as that impressed upon the external circuit; and if the generator is compounded to give constant terminal voltage, the arrangement becomes analogous to the case of a machine with one field-exciting winding supplied from an independent source at constant potential, and a second field-exciting winding in series with the external circuit.

The calculations for both long- and short-shunt arrangements are practically the same; but, on account of greater simplicity, those for the former, with the generator assumed to be compounded for constant terminal voltage, will be given.

We have from page 62, $E = M n$; also, $V = E - (r_a + r_{se}) I_a$. Since the flux depends upon the ampere turns of excitation

$$M = M_o + M_x = u\,(I_{sh}\,T_{sh} + I_{se}\,T_{se}), \quad\dots\dots\dots\dots\dots\dots (18)$$

in which u is a variable quantity representing, at various stages of the magnetization, the numerical relation between the flux and excitation of the magnetic circuit for a particular dynamo. Consequently, when the external current is zero, we have:

$$M_o = u_o\,I_{sh}\,T_{sh}.$$

M is proportional to the flux entering the armature from one pole, which in compounded machines is not a constant quantity. It is due to the combined effects of the shunt and series ampere-turns; that is, $M = M_1 + M_x$, in which M_1 is proportional to the shunt ampere-turns, and M_x is proportional to the series ampere-turns.

From pages 10, 61, and 62, it is clear that,

$$M_x = \frac{0.4\pi\,I_{se}\,T_{se}}{\Sigma\,\dfrac{l}{\mu\,A}} \cdot \frac{Z\,p}{10^8 .\,c},$$

and

$$M_1 = \frac{0.4\pi\,I_{sh}\,T_{sh}}{\Sigma\,\dfrac{l}{\mu\,A}} \cdot \frac{Z\,p}{10^8 .\,c},$$

where μ is the *average* value of the gross permeability (iron and air together), between its two extreme values—that is, when I = zero, and I = maximum.

Adding the two preceding equations, we have:

$$M = M_e + M_x = \frac{Z\,p\,0.4\,\pi}{10^8 c\,\Sigma\,\frac{l}{\mu\,A}}(I_{se}\,T_{se} + I_{sh}\,T_{sh}).$$

Replacing the factor $\frac{Z\,p\,0.4\,\pi}{10^8\,c\,\Sigma\,\frac{l}{\mu\,A}}$ by u, the result is:

$$M = u\,(I_{sh}\,T_{sh} + I_{se}\,T_{se}),\text{ as above.}$$

Substituting the values of E and M, there is obtained:

$$V = n\,u\,I_{sh}\,T_{sh} + n\,u\,I_a\,T_{se} - (r_a + r_{se})\,I_a.$$

Inspecting this equation, we note that it is composed of three terms. The first contains as variable factors the speed of rotation and the shunt current, which latter may be kept constant if the terminal voltage can be made constant. The second and third terms contain as a variable factor, the current I_a, while the second contains also the speed as a variable. It is noted, however, that the algebraic signs of the second and third terms are opposite, and that, if the speed of rotation is constant, the latter terms contain the only variables. Therefore, in order that V may remain constant throughout all changes of load within the rating of the machine, these terms must cancel. That is, $n\,u\,T_{se} = r_a + r_{se}$ is an equation of condition for constant V at constant n. Dividing both sides by $n\,u$, or by $u\,T_{se}$, there results:

$$T_{se} = \frac{r_a + r_{se}}{n} \cdot \frac{1}{u}\text{ ; or, } n = \frac{r_a + r_{se}}{T_{se}} \cdot \frac{1}{u}\,.\;\ldots\ldots\ldots\ldots\text{(19)}$$

When the external current is zero,

$$V = n\,M_o - (r_a + r_{se})\,I_a\,;$$

and assuming the drops due to the resistances of the armature and series field-windings to be zero (since they are negligibly small when the external current is zero), we have:

$$V = n\,u_o\,I_{sh}\,T_{sh} = I_{sh}\,r_{sh}.$$

Substituting value of n from Equation 19, we have:

$$\frac{r_{sh}}{T_{sh}} \cdot \frac{1}{u_o} = \frac{r_a + r_{se}}{T_{se}} \cdot \frac{1}{u}\text{ ; or, } \frac{T_{sh}}{T_{se}} = \frac{r_{sh}}{r_a + r_{se}} \cdot \frac{u}{u_o}\;\ldots\ldots\text{(20)}$$

which is the final equation of condition that V shall be constant.

As u_0 is proportional to μ_0, the permeability of the magnetic circuit when the external current is zero, and as u is proportional to μ, the average permeability over the working range, it follows that if there were no alteration due to saturation, we should have $u = u_0$.

Thus far we have assumed that the difference between the generated e. m. f. and the terminal voltage of the machine was dependent upon the resistances of the armature and series-field windings; but, as we have seen on page 49, there is also a drop due to the armature demagnetizing action. In order to take account of this, we must remember that if the angle of lead of the brushes be λ, the demagnetizing conductors will be confined within a belt 2λ (*i.e.*, $Z\lambda \div 90°$). Then, if the number of paths through the armature be c, each conductor will carry $I_a \div c = I_1$ amperes; and the number of demagnetizing ampere-turns will be $2DI_1$, where D is the number of armature conductors within the angle λ. In order to compensate for this action, a number of turns must be added to the series regulating turns, such that the m. m. f. produced by the external current flowing through them shall be exactly equal but opposed to that produced by the demagnetizing tendency of the armature. That is, the compensating turns must be at least,

$$\frac{2 I_1 D}{I} = \frac{2 D}{c}.$$

Owing, however, to the effect of magnetic leakage, the total m. m. f. of this compensating winding will not be sufficient to void the armature demagnetizing effect. This leakage may be provided for by multiplying $2 D \div c$ by ν, the coefficient of magnetic leakage. Hence we must substitute for T_{se} in Equation 20, $T_{se} - \frac{2 \nu D}{\mu}$, in order to compensate for these effects.

Should it be required to have the generator over-compound or under-compound, the additional series-turns will be either more or less than those given by the revised Equation 20, depending upon the amount of over- or under-compounding, examples of which will be considered under *Design*. In the above discussion, we tacitly assumed that the speed of rotation was maintained constant. This is in general not the case, however, the speed of the prime mover falling off as the load on the generator increases, producing a diminution in the generated e. m. f. In addition, the load is frequently remote from the dynamo, necessitating feeders between the machine and load, with a consequent drop in voltage. In order to compensate for these factors which tend to lower the voltage at the point of application of the power, it is customary to over-compound generators so that their terminal voltage at rated load is from 3 to 15 per cent in excess of the no-load value. The lower values are usual for generators supplying lighting circuits, while the higher ones are for those employed in railway systems.

CALCULATIONS OF THE MAGNETIC CIRCUIT

Forms of Field-Magnets.—*General.* Before discussing the application of the formulæ for the magnetic circuit, already given, to actual machines, let us consider the various shapes in which field-magnets and frames are usually found.

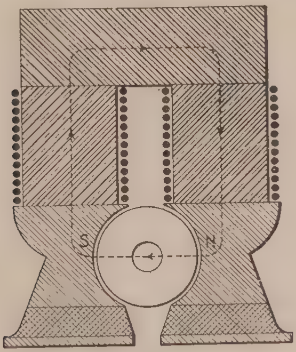

Fig. 100. Under-Type Bipolar Dynamo.

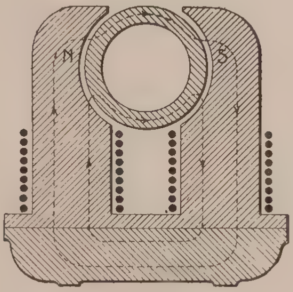

Fig. 101. Over-Type Bipolar Dynamo.

The form of a field-magnet depends primarily upon whether it is *bipolar* or *multipolar.* Prior to about 1890, the former type was in universal use for all direct-current machines, even up to large sizes; but now it is generally restricted to machines of less than 5 kilowatts output, larger sizes being made multipolar to save material, as explained later.

Bipolar field-magnets may be of the simple horseshoe type, placed as in the early Edison machines (Fig. 100); or may be turned with the pole-pieces upward, known as the *inverted* or *over-type* (Fig. 101); or the horseshoe may be laid on its side (Fig. 102). This latter type produces an unsymmetrical machine, and, in addition, the entire base and bearings are connected to one of the pole-pieces, exposing a large surface which materially increases the magnetic leakage. This type is interesting, however, from the fact that it has but a single field-coil. The same form is also arranged with the core horizontal, the armature being either under or over the latter, in which case the supports for the bearings must be of some non-magnetic material such as brass, since they extend from one pole-piece to the other.

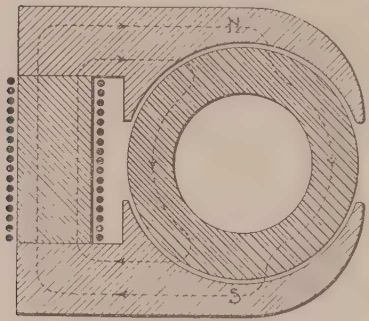

Fig. 102. Single Exciting-Coil Type Bipolar Dynamo.

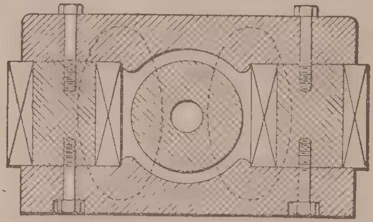

Fig. 103. Manchester Type of Field-Magnet.

These forms, excepting the over-type, are open to the objection that, if set upon an iron base, the base would act as a magnetic short-circuit, and thus rob the armature of a considerable portion of the magnetic flux. In the Edison machines, this difficulty was partly overcome by interposing thick pieces of zinc between the pole-pieces and the base; but Hopkinson* found that even with this arrangement,

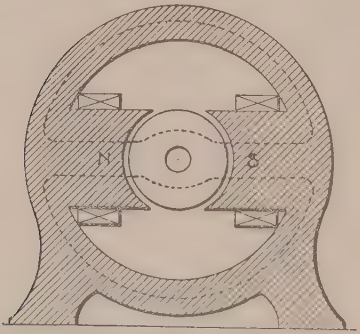

Fig. 104. Bipolar Ring Field-Magnet.

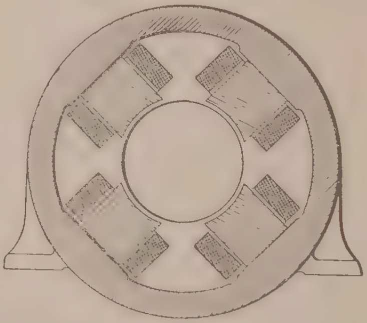

Fig. 105. Four-Pole Ring Field-Magnet.

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*Philosophical Transactions of the Royal Society, May 6, 1886.

the leakage through the base was over 10 per cent of the total flux. The over-type, on the other hand, has but small magnetic leakage of this character, since the pole-pieces are far removed from the base bearings or other magnetic conductors.

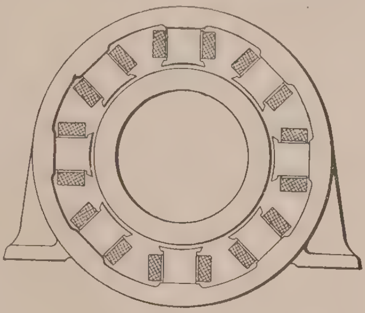
Fig. 106. Multipolar Ring Field-Magnet.

Fig. 103 represents a radically different form of bipolar magnet, called the *Manchester* type, from its place of manufacture in England. The construction is extremely solid, and offers good protection to the machine; but it has the undesirable feature of having two magnetic circuits in parallel, producing consequent poles and requiring the full number of ampere-turns for each circuit. Hence the total number is doubled; but each is only $\sqrt{\frac{1}{2}}$ times as long, because the cross-section of each core is one-half that of an equivalent single core. The required length of wire is thus $2 \times \sqrt{\frac{1}{2}} = 1.41$ times as great for the double magnetic circuit. This form also has considerable magnetic leakage, the entire base and bearings being connected to one of the pole-pieces.

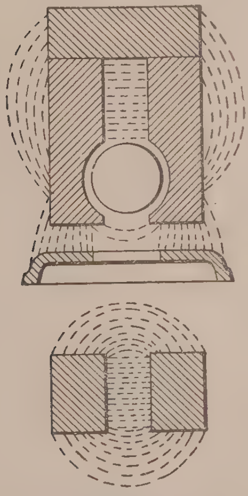
Fig. 107. Magnetic Leakage or Stray Flux in Bipolar Field.

The modern tendency has been to draw away from these early designs, and to adopt machines that are wholly or partially enclosed. Figs. 104, 105, 106 represent respectively the bipolar, four-pole and multipolar ring arrangements of present-day practice, the bipolar type being restricted to machines of small output, as noted above. This ring arrangement has the advantages of strength, simplicity, symmetrical appearance, and minimum magnetic leakage, since the pole-pieces have the least possible surface and the path of the magnetic flux is shorter, more symmetrical, and more natural.

Magnetic Leakage. The function of the field-magnet is, as we have seen, to produce a flux which the armature conductors cut in order to generate an e. m. f. This flux is called the *useful* flux. In addition to this useful flux, there is a *stray* flux from all parts of the field system (Figs. 107, 108), the m. m. f. of the exciting ampere-turns having to produce both these fluxes. If we call ϕ_m the flux in the magnet-core, ϕ_a the flux in the armature, and ϕ_s the flux which strays, we have:

$$\phi_m = \phi_a + \phi_s$$

The ratio between the total flux and the useful flux is called the *coefficient of magnetic leakage or dispersion*, that is,

$$\nu = \frac{\phi_m}{\phi_a}.$$

It is a number greater than unity, and varies in value from 1.15 in ring types (Figs. 104–106), to 1.7 in the Manchester and under-types (Figs. 100–103).

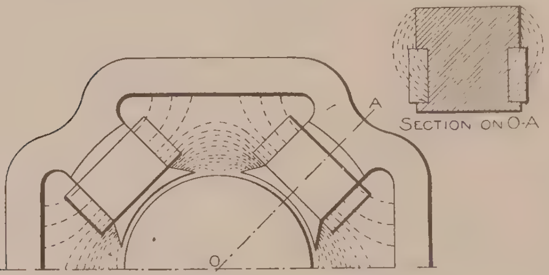

Fig. 108. Magnetic Leakage or Stray Flux in Four-Pole Field.

The magnitude of the stray field depends chiefly (*a*) upon the shape of the magnet-limbs; thus circular cores, for example, will have less leakage than those of rectangular cross-section, on account of the smaller area of the side flanks; (*b*) upon the length of the air-gap, because the higher the reluctance of the latter, the greater the tendency of the flux to take alternative paths; (*c*) upon the degree of saturation to which the field system is pushed, because the magnetic conductivity of the leakage paths in air is constant, while that of the iron cores decreases as the saturation point is approached. It is evident, therefore, that the coefficient of dispersion not only varies with different types of machine, but is not generally constant even in a given machine, since it rises with the excitation. Moreover, when a large armature current flows, the demagnetizing action of the latter directly aids dispersion, as it usually produces a m. m. f. opposed to that of the main flux, which tends to blow aside the latter.

The only accurate method of determining the dispersion factor of any machine is by experiment.* For purposes of design, however,

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*For various methods of procedure, see S. P. Thompson's *Dynamo-Electric Machinery*, Vol. I, p. 134, New York, 1904.

one must resort to the results of experiments performed on machines similar to the one being designed. Table II gives approximate values of dispersion coefficients for machines of the modern type (*i.e.*, multipolar frames), and — for comparison — values for corresponding machines of the other types mentioned.*

TABLE II

Dispersion Coefficients

Output in Kilowatts	Multipolar Type Figs. 104, 105, 106	Overtype Fig. 101	Undertype Fig. 100	Single-Magnet Type Fig. 102	Manchester Type Fig. 103
1	1.35				
2	1.25				
5	1.20	1.40	1.60	1.55	1.70
7	1.18				
10	1.16				
25	1.15	1.28	1.45	1.40	1.55
50	1.14				
100	1.12	1.22	1.35	1.32	1.45
200	1.11				
300	1.10		1.25		
500	1.09				
1,000	1.08				

It is seen that the magnetic dispersion is greater with the smaller sizes of machines, because the surfaces from which it occurs are relatively longer compared with the total flux. It is also greater with cast-iron magnets and pole-pieces and with smooth-core armatures.

It is theoretically possible to predetermine the dispersion of a given machine from the working drawings,† the calculations being based upon the principle that where a circuit offers alternative paths, the flux will divide itself between the paths in the proportion of their relative magnetic conductance or permeance. In fact, the theory of parallel electrical circuits is here applicable. Various rules have been devised for this purpose; but the manufacturers' designer usually contents himself with referring to tables such as that given above.

Exciting Ampere-Turns. The determination of the exciting ampere-turns for a machine is a simple matter if we know the dispersion coefficient and the magnetic properties (as shown by the B–H curve) of the materials forming parts of the magnetic circuit. See Fig. 112.

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*Dynamo-Electric Machinery; S. P. Thompson, New York, 1904, Vol. I, p. 138.

†*Dynamo-Electric Machines*, A. E. Wiener, 2d ed., p. 217.

The simplest mode of procedure is to fix approximately the flux necessary to pass through the armature in order to produce the required e. m. f.* Knowing this value, and also the size of the machine, we may select from Table II a suitable dispersion coefficient, and thus find the flux required to be produced by the field winding. That is:

$$\phi_m = \nu \, \phi_a$$

The next step is to allow a sufficient cross-section of material in the various parts to carry this flux at a reasonable flux-density. Knowing the latter at once fixes the reluctance, and the necessary number of ampere-turns is found by solving the equation connecting the flux, m. m. f., and reluctance of each portion of the circuit, given on page 10. That is,

$$\text{Ampere-turns} = I\,T = \frac{\phi\, l}{1.257\, A \mu} = \frac{B\, A\, l}{1.257\; A\, \mu} = \frac{B\, l}{1.257\; \mu}.$$

Where B is the flux-density per square centimeter, and l the length of the part in centimeters, the sum of the ampere-turns required for the different parts will then give the total ampere-turns for that circuit. The magnetic path from one pole to its neighbor of opposite polarity and return, is alone considered as indicated in Figs. 104, 105, 106 (assuming a ring-type yoke). Hence the total ampere-turns for this circuit will be those necessary per pair of poles. In other words, each field-coil must have one-half of this total value.

As average values for the magnetic densities in the various parts of continuous-current generators, we may take the figures of Table III, departures from which are, however, often necessitated by circumstances.

If the particular solution thus arrived at is not suited to the various conditions, a slight change in the original assumptions will bring one nearer to the proper value. In fact, the more preliminary calculations that are made, the more nearly perfect and the more reliable will be the final figures; furthermore, it is always wise to make assumptions both sides of the accepted value, to make sure that it is right.

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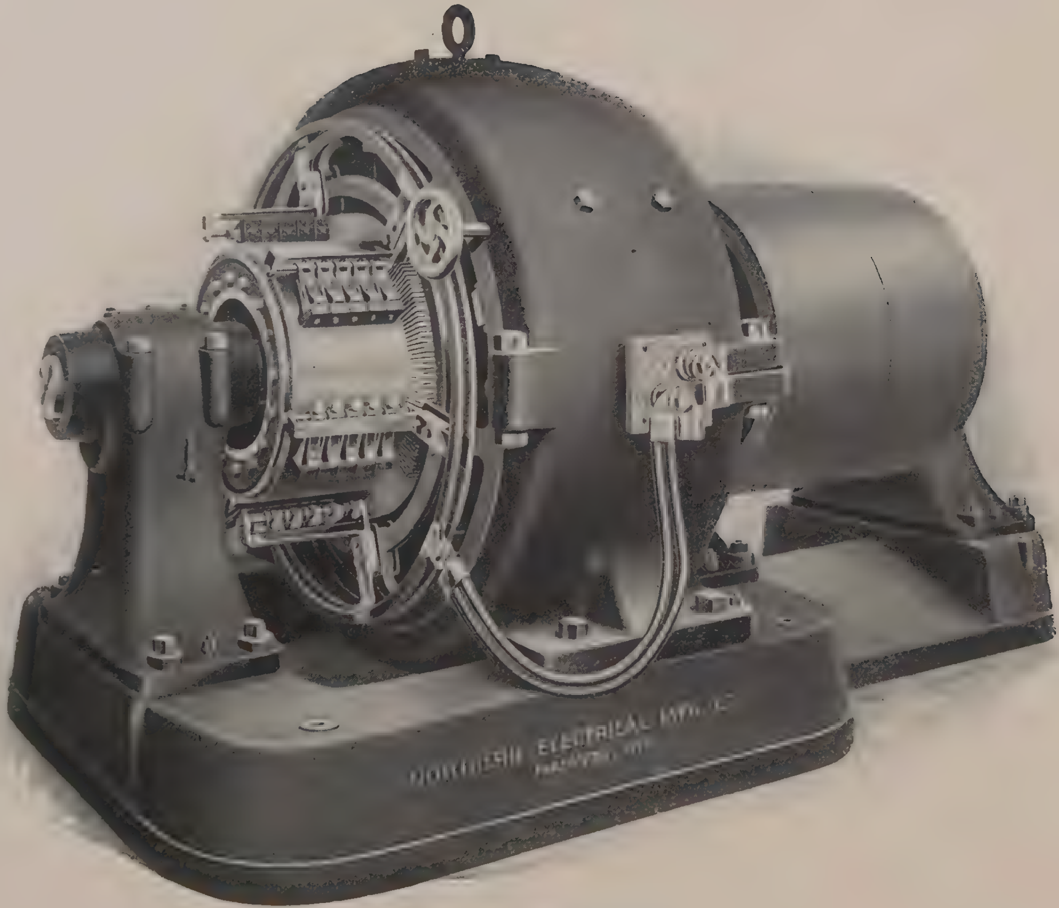
*See Equations 1 and 2, page 62.



BELTED GENERATOR.

Ring Type, Three Bearing, Six Pole.

As these assumptions carry with them the selection of the magnetic dimensions of the machine, it will be well to consider these here.

TABLE III

Average Flux-Densities in Various Parts of Continuous-Current Generators

Flux-Density, in:—	Lines per Square Inch	Material
Armature body	50,000 to 95,000	Soft sheet iron or mild steel
Armature teeth	125,000	Do.
Air-gap	40,000 to 55,000	Air
Magnet-cores	75,000 to 100,000	Cast steel or wrought iron
Magnet-yoke	70,000 to 90,000	If cast steel or wrought iron
	35,000 to 50,000	If cast iron

(*a*) *Yoke.* In all machines of the ring (yoke) type, the yoke carries only one-half the total flux, as can be seen by reference to Figs. 104 to 106. The magnetic length is the mean length of path.

(*b*) *Magnet-Cores.* As each core carries the whole flux for one pole-face, the entire section of one core is considered. The length of the magnetic path in the magnet-cores is, however, twice the length of one core.

(*c*) *Air-Gap.* Since slotted armatures are the type used almost exclusively at present, the magnetic area of this portion will be equal to the pole-face area. The total magnetic length of these gaps is taken as twice the distance from iron to iron, measured perpendicular to the armature periphery.

(*d*) *Armature Core.* Here, also, the magnetic flux divides into two or a multiple of two paths (for the ring-yoke design), so that the magnetic area carries only one-half the flux entering the armature from one pole-face. The magnetic section is also less than the gross section, on account of the insulation of the core-discs* and the presence of ventilating ducts.† If the latter are absent, it is usual to allow 10 per cent as space loss if the insulation is varnish, and 15 per cent if it is paper. When the air-ducts are present, 25 per cent may be assumed for preliminary calculations with varnish insulation, and 35 per cent with paper insulation. The magnetic length is the length of the mean path lying between the roots of the teeth and the periphery of the internal hole.*

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* See page 14 for reason for laminating and insulating core-discs.

† See page 171 for design, etc., of ventilating ducts.

(*e*) *Teeth.* The total length traversed by the flux in this portion of the circuit is equal to twice the depth of one tooth. The width of one tooth may be taken as the width at the root, the teeth being generally trapezoidal in shape. The number of teeth receiving the flux from one pole may be taken as the number lying immediately under the pole-face, *plus* one or two, depending upon the allowance for fringing.† The magnetic area of the teeth will therefore be the number so determined, *multiplied by* the product of the mean width of one tooth and the mean length of the armature, where the latter is the gross length *minus* the percentage allowed for insulation and air-ducts. Account must also be taken of the fact that when the teeth are operated at densities of 100,000 lines per square inch or more, part of the flux from the poles will take the alternative air-paths through the slots to the armature core, since at this high density their permeance is not insignificant compared with that of the teeth themselves. In other words, the ampere-turns calculated to force the flux through the teeth alone at high flux-densities would be in excess of the correct amount.

In order to find the true value of the flux-density in the teeth if we know the apparent flux-density, let us assume that:

$\propto$ = Ratio of net length to gross length of armature core;
B_t = True value of the tooth flux-density;
b_t = Width of a tooth, at the root;
b_s = Width of a slot;
h = Height or depth of a slot;
l = Net length of the armature parallel to the shaft;
ϕ_a = Flux entering the armature from one pole;
ϕ_t = Flux actually carried by the teeth, from one pole.

We then have:

$$\text{Iron section of one tooth} = b_t \times l.$$

$$\text{Air section of one slot} = \frac{b_s \times l}{\propto}.$$

The actual space forming an alternative path for the magnetic flux, per slot, will be given by the area of one slot (parallel to the pole-face) *plus* the area lost along one tooth by insulation and air-ducts; or,

---

*The "internal hole" is that portion of the armature between the center and inner edge of the core.

†"Fringing" means spreading of flux issuing from a pole-shoe.

$$\text{Section of air-space per slot} = \frac{b_s \times l}{\alpha} + (1-\alpha)\frac{b_t \times l}{\alpha}$$
$$= \frac{l\,(b_t + b_s - \alpha\, b_t)}{\alpha}.$$

Since the flux entering the armature from one pole will divide between the two paths inversely as the reluctance of the two, we have, as the flux in the air-space,

$$(\phi_a - \phi_t) \propto \frac{l\,(b_t + b_s - \alpha\, b_t)}{\alpha\, h};$$

and the true flux in the teeth,

$$\phi_t \propto \frac{b_t\; l\; \mu}{h},$$

in which μ is the actual permeability of the teeth when transmitting the flux ϕ_t.

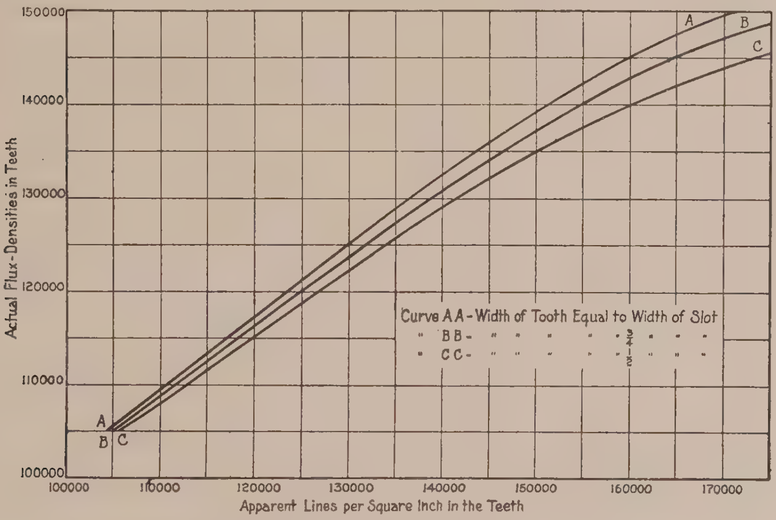

Fig. 109. Apparent and Actual Flux-Densities in Teeth.

Dividing the second equation by the first, we obtain,

$$\frac{\phi_t}{\phi_a - \phi_t} = \frac{\alpha\; b_t\; \mu}{b_t + b_s - \alpha\; b_t};$$
$$\phi_t\,(b_t + b_s - \alpha\; b_t + \alpha\; b_t\; \mu) = \phi_a\, \alpha\; b_t\, \mu$$
$$\frac{\phi_t}{\phi_a} = \frac{\alpha\, b_t\, \mu}{b_t + b_s - \alpha\; b_t + \alpha\; b_t\; \mu} = \frac{B_t}{B_a}.$$

Taking this last equation, and substituting for α 0.75 (a common value), and various ratios for $b_t \div b_s$, we obtain the curves given in Fig. 109, by assuming various values for B_t, finding the corresponding values of the permeability from Fig. 110, and then calculating B_a. If other values of α are used and greater accuracy is desired, where the actual B–H curve of the material of the teeth is known, these new quantities should be placed in the equation given above, and new curves drawn.

Example of Calculation. In order that the foregoing rules may be clearly understood, and to exemplify the use of the curves and the method of calculation, we shall take a concrete case of dynamo design. In Fig. 111 is given a dimensioned sketch of a modern six-pole continuous-current generator having a capacity of about 200 kw. Assuming that 12,500,000 lines are required to produce the rated e. m. f. in the armature, let us calculate the ampere-turns per pair of poles to produce this flux in the armature. From Table II, $\nu = 1.11$ approximately, and the data of the magnetic circuit around path A or path B is:

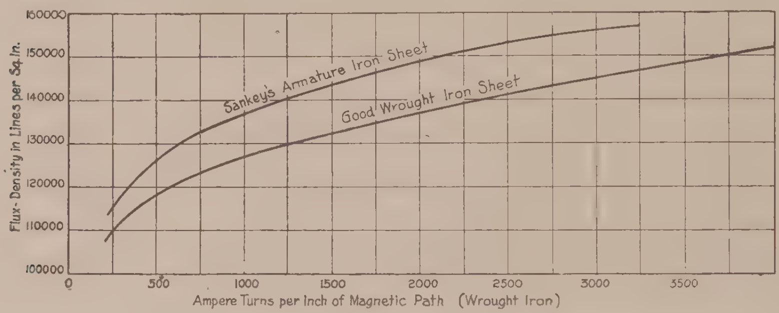

Fig. 110. Magnetization Curves at Very High Densities.

PART	MATERIAL	TOTAL FLUX
Yoke	Cast steel	6,937,500
Pole-cores	Cast steel	13,875,000
Pole-shoes	Cast steel	13,875,000
Air-gap	Air	12,500,000
Armature teeth	Sheet steel	12,500,000
Armature core	Sheet steel	6,250,000

We now estimate the magnetic lengths and areas as follows:

Yoke. From Table III, we assume the flux-density = 65,000; hence the cross-section of the yoke is

$$6,937,500 \div 65,000 = \text{approximately } 105 \text{ sq. in.} = A_y.$$

Consequently the dimensions of the yoke would be, say, 6 in. by 17.5 in., making the actual flux-density in the yoke,

$$B_y = 6,937,500 \div 105 = 65,200 \text{ lines per sq. in.}$$

The length of magnetic path, scaled off from the drawing, is

$$l_y = 55 \text{ in.}$$

Magnet-Cores. Assuming, from Table III, the flux-density in the teeth as 85,000 lines per sq. in., we have as the required area of cross-section of the magnet-cores,

$$13{,}875{,}000 \div 85{,}000 = 163.2 \text{ sq. in.}$$

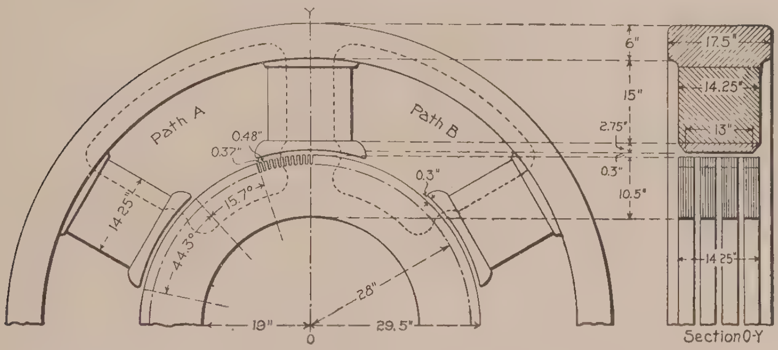

Fig. 111. Part of Magnetic Circuit of a Six-Pole Machine.

Selecting a circular section for the pole-cores, let us assume a diameter of, say, 14.25 inches, as giving an area of cross-section nearest to that above computed. This gives:

$$A_m = 159.5 \text{ sq. in., and}$$

$$B_m = \frac{13{,}875{,}000}{159.5} = 87{,}000 \text{ lines per sq. in.}$$

The length of magnetic path in the pole-cores is twice the length of one; so that,

$$l_m = 2 \times 15 = 30 \text{ in.}$$

Pole-Shoes. These are cast-steel extensions affixed to the magnet-cores to increase the air-gap area. The mean area of each shoe is,

$$A_s = 197.5 \text{ sq. in.;}$$

so that,

$$B_s = \frac{13{,}875{,}000}{197.5} = 70{,}400 \text{ lines per sq. in.}$$

The mean length of magnetic path per shoe is 2.75 in. Hence we have,

$$l_s = 2 \times 2.75 = 5.5 \text{ in.}$$

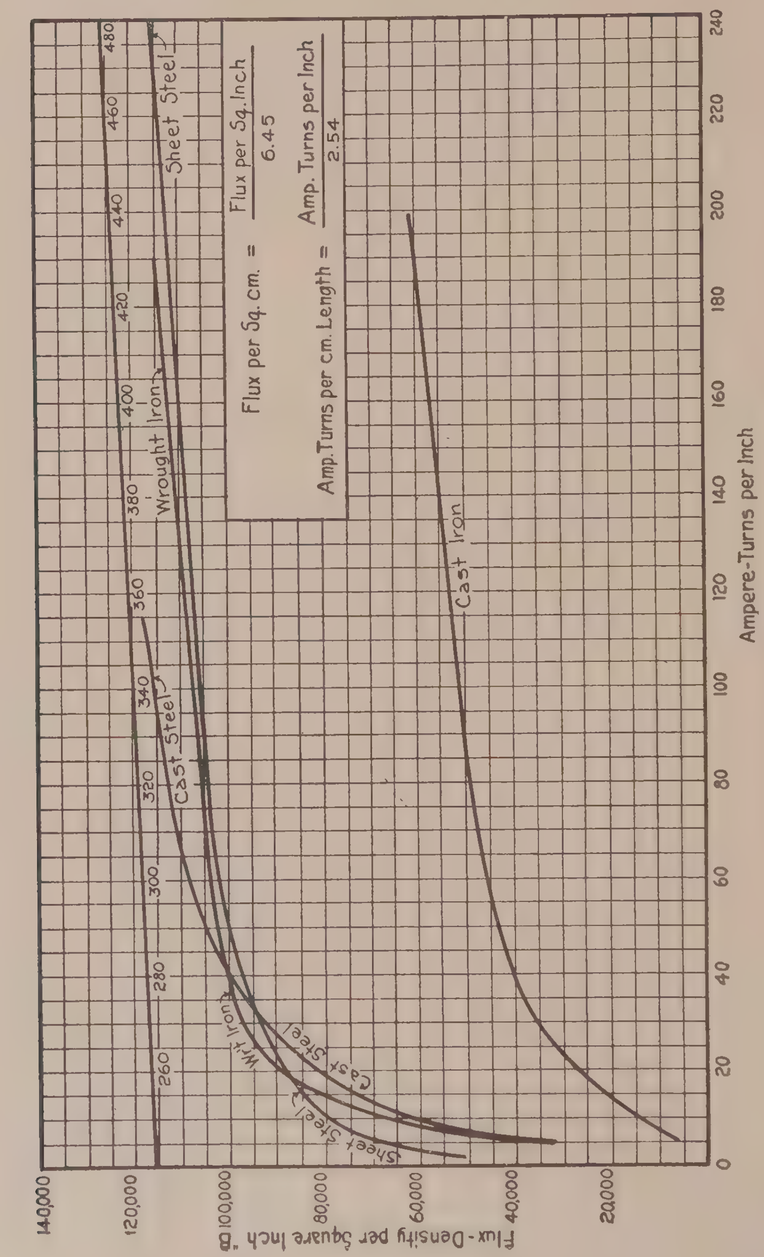

Fig. 112. Magnetization Curves of Irons and Steels.

Air-Gaps. The magnetic area of the air-gap being the area of the pole-face, we have it equal to 300 sq. in. Hence

$$B_g = 12{,}500{,}000 \div 300 = 41{,}700 \text{ lines per sq. in.}$$

The magnetic length through air in path A or B is twice the length of an air-gap; that is,

$$l_g = 2 \times 0.3 \text{ in.} = 0.6 \text{ in.}$$

Armature Teeth. The iron area of the 28 teeth acted upon by one pole, if the width of one tooth at its root is 0.326, is:

$$A_t = 0.326 \times 28 \times 14.25 \times 0.75 = 97.4 \text{ sq. in.}$$

Therefore,

$$B_t = \frac{12{,}500{,}000}{97.4} = 128{,}500 \text{ ``apparent'' lines per sq. in.}$$

Referring to Fig. 109, we see, since a tooth is as wide as a slot, that $B_t = 124{,}200$ actual lines per square inch in the teeth.

For the magnetic length, we have,

$$l_t = 2 \times 1.5 = 3.0 \text{ in}$$

Armature Core. The magnetic area is

$$A_c = 9 \times 14.25 \times 0.75 = 96.3 \text{ sq. in}$$

Hence,

$$B_c = \tfrac{1}{2} \times \frac{12{,}500{,}000}{96.3} = 65{,}000 \text{ lines per sq. in.,}$$

as the flux divides and takes two paths through the armature core.

The mean length of the magnetic path as obtained from the drawing, is:

$$l_c = 33 \text{ in.}$$

The preceding data may now be tabulated as follows:

PART	MATERIAL	MAGNETIC AREA IN SQ. IN.	B IN LINES PER SQ. IN.	LENGTH OF PATH IN IN.
Yoke	Cast Steel	105	65,200	55
Pole-core (1)	“ “	159.5	87,000	15
Pole shoe (1)	“ “	197.5	70,400	2.75
Air-gap (1)	Air	300	41,700	0.3
Arm. Teeth	Sheet steel	97.4	128,500	1.5
Arm. Core	“ “	96.3	65,000	33

By reference to the magnetization curves (Fig. 112), the ampere-turns per inch of length for the various materials at the flux-densities determined may be found, and the ampere-turns for total length of path computed. The results may then be tabulated as follows:

PART	FLUX-DENSITY IN LINES PER SQ. IN.	AMPERE-TURNS PER IN. LENGTH OF MAGNETIC PATH	LENGTH OF PATH IN INCHES	AMPERE-TURNS FOR TOTAL PATH
Yoke	65,200	12	$55\frac{1}{8}$	661
Pole-cores (2)	87,000	21.5	30	645
Pole-shoes (2)	70,400	13.5	5.5	75
Air-gaps (2)*	41,700	13,080	0.6	7,745
Arm. Teeth (2)	128,500	589	3	1,767
Arm. Core	65,000	8	33	264
		Ampere-turns per pair of poles,		11,157

Coil Winding Calculations. In series field-coils the whole of the external current, or a definite part of it, is used for the production of a m. m. f., so that the number of turns of wire or strip is found by dividing the requisite number of ampere-turns at any given load by this current. Furthermore, this wire or conductor must be of sufficient size to carry safely, efficiently, and without overheating, the given current. The series-wound generator is at present in general use for arc-lighting machines; and as the current in this case is usually about 10 amperes, it has been found by experience that, depending upon the depth of the winding, No. 10 or No. 8 B. & S. gauge wire are the correct sizes to use.

If the machine were to be separately excited, it is probable that the e. m. f. of the exciter would be specified, and we should have practically the shunt case. If, however, the current were given, the determination would be the same as in the case of the series winding above.

Shunt Winding Calculations. The determination of the best size of wire for a shunt winding is far more difficult than for a series one, in that merely the ampere-turns and the voltage applied to the terminals of the coil are given, while the space allotted to the winding and the heating limits must be kept within definite bounds. Various methods have been suggested, but none are very satisfactory. One of the simplest is as follows: The temperature of the field coils for

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*In computing ampere-turns per inch length of the air-gap, it must be remembered that for air $\mu = 1$; so that in inch-units we have,

$$IT_g = 0.3133 \times B_g \times l_g \, .$$

The number 0.3133 is called the *gap-coefficient*, and represents the number of ampere-turns per inch length of path, requisite for a flux-density of one line per square inch in air.

continuous operation at rated load may be assumed to be 75° C.—that is, a 50° C. rise above a room temperature of 25° C. At this temperature the resistance of a mil-foot of copper wire (that is, a wire one foot long and 0.001 inch in diameter) is 12.56 ohms. Hence,

$$R = \frac{12.56 \times l}{\text{Circ. mils}},$$

in which l is the length of the conductor in feet, and "Circ. mils" is the area of cross-section in circular mils, which is equal to the diameter in mils squared. The current traversing the wire when a voltage V' is applied at its terminals, is,

$$I = \frac{V' \times \text{Circ. mils}}{12.56 \times l}.$$

It is also evident that the ampere-turns in any winding are numerically equal to the amperes that would result if a single turn of wire were supposed to be subjected to the given voltage, because two turns would have twice the resistance and would take one-half the current; and so on for any number. Hence,

$$\text{Ampere-turns} = \frac{V' \times \text{Circ. mils}}{12.56 \times l},$$

in which l represents the mean length of one turn in feet. By transposition we obtain the cross-section of the wire required—that is:

$$\text{Circ. mils} = \frac{\text{Ampere-turns} \times l \times 12.56}{V'}.$$

Example. An 8-pole 150 kw. shunt generator required 808 ampere-turns per pair of poles when its terminal voltage was 115. The poles were $9\frac{1}{4}$ inches wide, and 10 inches long parallel to the shaft. Allowing a depth of winding of about 2 inches and a spool thickness of about $\frac{1}{2}$ inch, the mean length of one turn would be nearly 50.5 inches, the poles being rectangular. Then, at rated voltage, V' per pair of field-exciting coils is $115 \div 4 = 28.75$ volts, and we have:

$$\text{Circ. mils} = \frac{808 \times 50.5 \times 12.56}{28.75} = 17{,}850.$$

Referring to a wire-gauge table, we see that the wire having an area of cross-section in circular mils nearest this figure is No. 7 B. & S., for which circ. mils = 20,820.

In applying the above formula to the shunt winding for a dynamo, allowance must be made for the resistance of the rheostat which is usually put in the shunt circuit to regulate the e. m. f.

This resistance will consume from 20 to 30 per cent of the no-load voltage; and the value of V' to be substituted in the formula should therefore be a corresponding amount lower, unless the rated load voltage be used. In this case the resistance of the rheostat is determined by the resistance which it is necessary to add to that of the field-winding in order to keep the generated e. m. f. at the proper point for all other loads.

Space-Factor. In all cases where insulated conductors, whether strip or wire, are used, the space taken up by the conductor proper is always a fraction of the whole space occupied by the entire winding. This fraction will obviously depend upon the shapes of the conductors and the space set apart for the winding, and also upon the thickness of the insulation. The ratio of net cross-sectional area of copper in any such space to the gross section, is called the *space-factor.*

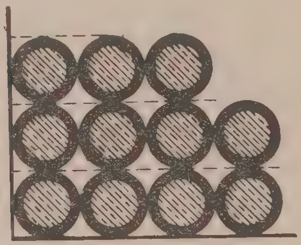


Fig. 113. Square Order of Bedding.

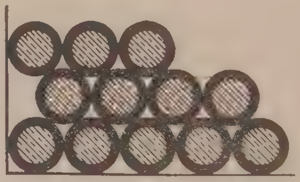


Fig. 114. Hexagonal Order of Bedding.

In winding bobbins for field-magnet coils, the space-factor depends largely upon whether square or round wire is used. If the former, the space wasted is less, and the heating of the coil is reduced (for a given number of turns carrying a given current, etc.), since there is less cross-section filled with air or insulation, either of which is a bad conductor of heat. If round wires are used (as is generally the practice), the space-factor will be determined chiefly by the ratio between the relative thicknesses of the wire and its insulation, and also by the partial bedding of one layer of wires between those of the layer below.

Suppose the round wires to be wound so as to lie in the square order without any bedding, as in Fig. 113. Then, if the diameter of the bare wire is d, and the insulated diameter is d_1, the ideal space-factor would be:

$$\sigma = 0.7854 \frac{d^2}{d_1^2}, \tag{21}$$

because the area of each small circle is $\pi \frac{d^2}{4} = 0.7854\ d^2$, and the area of the small square enclosing each outer circle is d_1^2. Suppose, however, an extreme case of bedding, as in Fig. 114, where the wires lie in hexagonal order. By similar reasoning, the space-factor would then be:

$$\sigma = 0.906 \frac{d^2}{d_1^2}.$$

If rectangular strip is used, there is no bedding, and no wasted space except where the end of one layer of a coil extends to the layer above. If the area of cross-section of the bare conductor is *ab*, and the area of the same, insulated, is *a′ b′*, the space-factor is simply *ab* ÷ *a′ b′*. In practice it has been found that edge-wound strip gives the highest space-factor, ranging from 0.83 to 0.93.

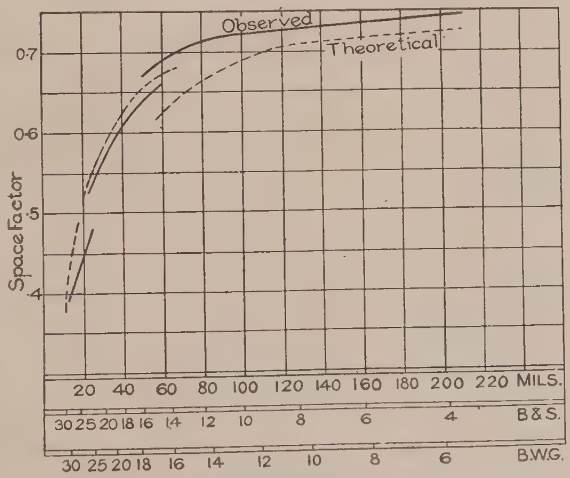


Fig. 115. Curves Showing Space-Factors for Round Wires of Various Gauges.

In practice, with round wires, it is found, however, that even the most experienced winders produce a bedding of seldom over 3 per cent; so that the safest course is to assume no bedding, and to take the space factor as given above unless it is actually known.

Some actual figures have been put into graphical form by Dr. S. S. Wheeler, and these are given in Fig. 115. Here the full lines represent the values by the formula assuming the square order; and the broken lines, the observed values. It is seen that the larger sizes of wire do actually bed a little, while with smaller sizes the bedding is negative.

Connections of Exciting Coils. It is the almost invariable custom to connect all the field-magnet exciting coils of the same type in series with each other, so that the magnetizing current is the same throughout. Then, if the number of turns per spool is the same, the flux per pole will be uniform. They must also be connected up so as to produce alternate north and south poles, so that if all the coils are wound in the same direction, and similarly placed, the connections will come alternately at the yoke-end and the pole-face end of the bobbin, as in Fig. 116.

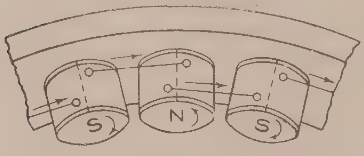


Fig. 116. Connections of Field-Magnet Coils.

Excitation Losses. Having computed the resistance of the shunt winding (r_{sh}) by the previously explained method, we have $\frac{V}{r_{sh}} \times V = \frac{V^2}{r_{sh}}$ as the watts actually expended in the shunt field-coils, V being the terminal voltage of the generator. To this loss must be added the one in the shunt-regulating resistance, and also the loss in the series-regulating coils, if any, in order to give the total watts required in excitation. For shunt-wound machines, the watts required in excitation vary in practice from 1 to 8 per cent or more of the output, depending upon the capacity of the machine. As a guide in this direction, Table IV has been constructed, giving the *maximum permissible* excitation losses.

TABLE IV

Excitation Losses

Output of Machine in Kilowatts	Excitation Losses in per cent of Rated Load Output
5	6
10	5
20	4
30	3.5
50	3.0
100	2.75
200	2.50
300	2.25
500	2.00
1,000	1.75
2,000	1.50

Heating of Magnet-Coils. The heat developed in field-magnet coils is dissipated in two ways: It is either carried by conduction through the copper and the insulation, and then by radiation and convection to the outer air, or it is conducted to the iron portions of the machine nearby and radiated off by these. In either case the amount of heat produced in the coil is equal, in watts, to the product of the resistance and the square of the current, while the rate at which the heat is lost cannot be very accurately calculated.

In order to compute the temperature which a field-coil finally reaches, let w_{m} = watts wasted in field-coils at rated load of machine;

A'_{m} = Radiating area of all the bobbins, in square inches:

θ_{m} = Final temperature rise above surrounding air (usually 50° C.).

Then

$$\theta_{\mathrm{m}} \propto w_{\mathrm{m}},$$

$$\theta_{\mathrm{m}} \propto \frac{1}{A'_{\mathrm{m}}}.$$

So that,

$$\theta_{\mathrm{m}} \propto \frac{w_m}{A'_{\mathrm{m}}};$$

or,

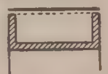
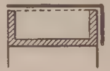
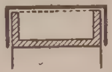
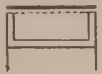
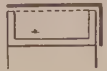
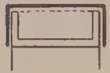
$$\theta_{\mathrm{m}} = h\frac{w_{\mathrm{m}}}{A'_{\mathrm{m}}},$$

where h is a constant depending upon the depth of the winding, upon the cooling action due to the armature rotation, and upon the condition of the surrounding air. It is the temperature above that of the sorrounding air to which the coil would be raised if radiating 1 watt per square inch.

Experience has shown that a certain rise in temperature is allowable, this being usually put at 50° C. or 90° F. above the temperature of the surrounding air. Tests have also demonstrated that this rise in temperature is not usually exceeded if a certain surface of coil is allowed for each watt converted into heat. The difficulty in fixing this is due to the way in which the heat is dissipated, as before noted. Also, authorities differ in regard to what surface shall be considered as radiating, in some cases going so far as to count only the external cylindrical surface of the coil. As a matter of fact, the internal surface of the coil, next to the poles, usually dissipates more heat in a given time than the external surface, so that the total area should be reckoned. This may be done by assuming a proper

TABLE V

Specific Temperature Increase in Magnet-Coils of Various Proportions at Unit Energy Loss per Sq. In. of Core Surface

CYLINDRICAL MAGNETS								RECTANGULAR AND OVAL MAGNETS	
Ratio of Winding Depth to Core Diameter	Winding Depth in Parts of Core Diameter	Ratio of External Coil Surface to Core Surface 	Ratio of Cylindrical Surface plus One End Surface of Coil to Core Surface 	Ratio of Cylindrical Surface and Both End Surfaces of Coil to Core Surface 	Increase of Magnet Temperature for Each Watt per Square Inch of Core Surface			Ratio of Radiating Surface to Core Surface	Temperature Increase for Unit Energy Dissipation
					Radiating Surface Consisting of				
					Cylindrical Coil Surface 	Cylindrical Surface plus One End Surface 	Cylindrical Surface and Both End Flanges 		
1 : 100	.01	1.02	1.03 to 1.05	1.04 to 1.07	75°	74° to 72°	73° to 71°	1.02	75°
1 : 50	.02	1.04	1.05 " 1.10	1.07 " 1.12	73	72 " 69	71 " 68	1.05	72
1 : 30	.033	1.067	1.07 " 1.15	1.10 " 1.20	71	70 " 65	69 " 63	1.1	69
1 : 20	.05	1.1	1.12 " 1.20	1.15 " 1.30	69	68 " 63	65 " 58	1.25	60
1 : 15	.067	1.133	1.15 " 1.25	1.20 " 1.40	67	65 " 60	63 " 53.5	1.5	50
1 : 12	.083	1.167	1.20 " 1.30	1.25 " 1.45	65	63 " 58	60 " 51.5	1.75	43
1 : 10	.1	1.2	1.25 " 1.40	1.30 " 1.55	63	60 " 53.5	58 " 48	2	37.5
1 : 9	.11	1.22	1.28 " 1.45	1.35 " 1.60	61.5	59 " 51.5	55.5 " 47	2.25	33
1 : 8	.125	1.25	1.30 " 1.50	1.40 " 1.70	60	58 " 50	53.5 " 44	2.5	30
1 : 7	.143	1.286	1.35 " 1.55	1.45 " 1.80	58.5	55.5 " 48.5	51.5 " 41.5	3	25
1 : 6	.167	1.33	1.40 " 1.60	1.50 " 1.90	56.5	53.5 " 39.5	50 " 39.5	3.5	21.5
1 : 5	.2	1.4	1.50 " 1.75	1.60 " 2	53.5	50 " 43	47 " 37.5	4	19
1 : 4	.25	1.5	1.65 " 2	1.80 " 2.5	50	45.5 " 37.5	41.5 " 30	5	15
1 : 3	.33	1.67	1.85 " 2.5	2 " 3	45	40.5 " 30	37.5 " 25	6	12.5
1 : 2	.5	2	2.25 " 3	2.5 " 4	37.5	33 " 19	30 " 19	8	9.5
1 : 1	1	3	3.5 " 5.5	4 " 8	25	21.5 " 13.5	19 " 9.5	10	7.5
3 : 2	1.5	4	5 " 8.5	6 " 12	19	15 " 9	12.5 " 6	12	6
2 : 1	2	5	6.5 " 12	8 " 18	15	11.5 " 6	9.5 " 4	15	5

value of h, which, according to W. B. Esson, is about 55 and according to Esterline 83, for ordinary bobbins; or by relying upon the experimental results given in Table V. Esson, in using this figure, counts as radiating surface only the external heat-radiating area, and not the end flanges and internal surfaces. Esterline includes in the radiating surface the external and internal areas and the flanges, counting the last two as radiating only one-half as much as a corresponding external area.

ARMATURE WINDINGS

Armature conductors—or *inductors*, as they are sometimes called—are almost universally made of copper. Their arrangement upon the armature, and the order in which they are connected together to form a complete winding, constitute one of the most involved subjects in the design of dynamo-electric machinery.

Classification. Armature windings may be classified according to the way the conductors are placed upon the armature core, as follows:

Ring Windings, in which the conductors are placed upon a ring-shaped core, passing through the interior of the ring in the form of a helix, and hence sometimes called *helical windings*.

Drum windings, having the conductors wound entirely upon the surface, or in slots upon the surface, of a cylindrical core.

Disc windings, where the conductors are arranged in a plane like the spokes of a wheel, the connections being similar to those in drum armatures.

Of all these types, the drum is almost exclusively used at the present time for the armature windings of continuous-current machines, since, in contradistinction to the ring winding, there are no internal return conductors to increase the amount of armature copper needed, and for the greater reason that formed coils are applicable, greatly reducing the first cost and facilitating insulation and repairs. A drum armature partly wound with formed coils is illustrated in Fig. 117.

Besides this grouping, we may also divide windings into *closed-coil* and *open-coil* types, depending upon whether the winding constitutes a closed or an open circuit. Closed-coil armatures are in almost general use for direct-current machines, since they give a steadier current and spark considerably less than the open-coil type.

The latter are used for direct-current arc-lighting machines and for star-wound alternators.

Armature Coil.—*Element of Winding.* A *winding element, section,* or *coil* is that portion of an armature winding which terminates at two commutator bars. In its simplest form it consists of two armature conductors (in drum windings), with the necessary end connections, so that the maximum number of armature coils is equal to one-half the number of armature conductors. In ring windings, an element may consist of only one armature conductor, the internal return portion being inactive (that is, cutting no flux) and therefore serving as an end connector. Such an element may also consist of 2 or $2n$ armature conductors in series for drum windings, or of n armature conductors in series for ring windings, where n is an integer; but this affects only the e. m. f. generated by the coil, the end connections of the section as a unit remaining unchanged. Similarly, the resistance of an element may be reduced by connecting several conductors in parallel; but this also does not affect the end connections of the coil as an element of winding; it merely increases the current-carrying capacity. In either case the *method* of winding

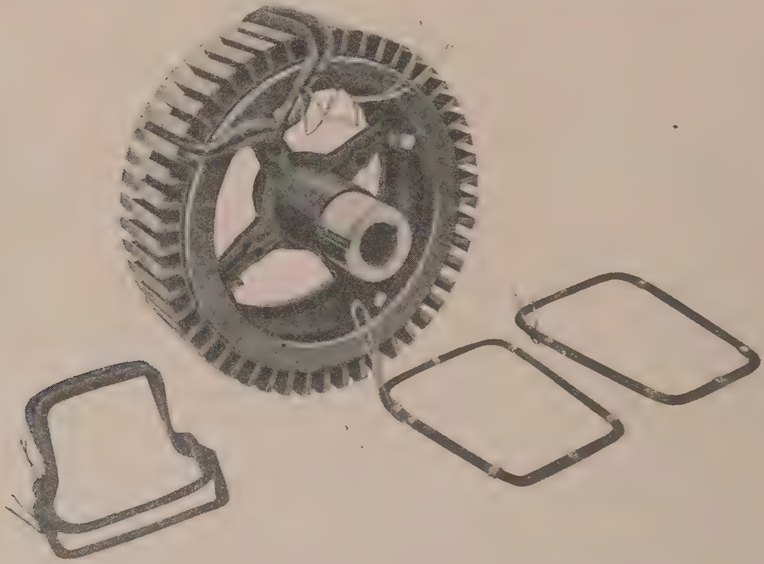
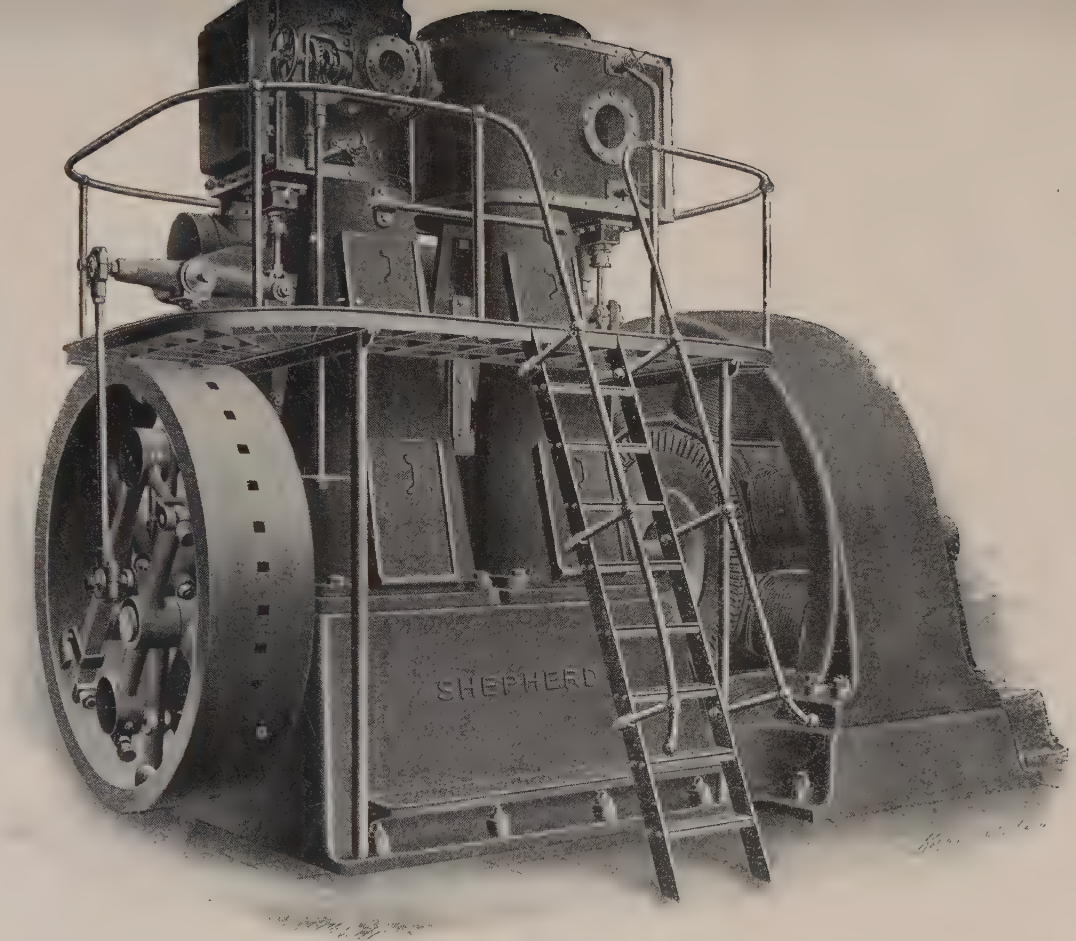


Fig. 117. Showing Method of Winding and Applying Formed Coils for an Armature Core.



VERTICAL CROSS-COMPOUND ENGINE DIRECT-CONNECTED TO 400 K.W. DYNAMO.

Shepherd Engineering Company,

is not altered by putting more turns of wire in series or in parallel in each section.

The whole theory of armature winding may therefore be said to resolve itself into a study of end connections; and in discussing drum windings, we shall consider an element consisting of two armature conductors with their end connections only.

Possible Number of Commutator Bars. We have seen that at each end of a section of winding there is a commutator bar. In the simplest form of ring-wound armature, each element of the winding contains only one armature conductor, so that the maximum number of commutator bars is Z, the rest of each element being equivalent to an end connection. The number of commutator bars in a ring winding may also be less than Z (where $Z =$ the number of armature conductors); but in any case it is $\frac{Z}{m}$, where m is 1 or an integer factor of Z.

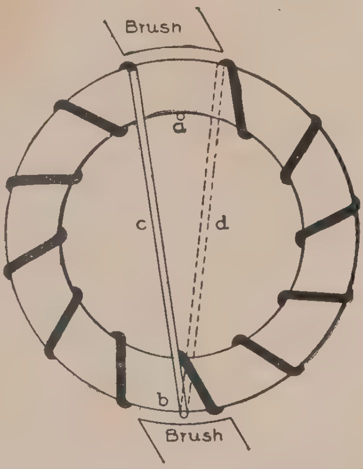


Fig. 118. Modification of Ring Winding to Form a Drum Winding.

In closed-coil drum windings, K, the number of commutator bars, has for its maximum value $\frac{Z}{2}$, and it may be $\frac{Z}{2m}$, for a drum-wound armature cannot have adjacent conductors connected to separate commutator segments and be a closed-coil winding. If each alternate armature conductor in a drum winding be considered as the return of its neighbor, the equivalent ring winding would be as indicated by coil in Fig. 118, and we then see that the armature would be short-circuited.

Field Step. In ring windings, the coils are wound around the armature core, so that they pass through its interior; but in drum windings the armature conductors are laid in slots on the surface of the core, and do not pass through the interior. It is plain, in the latter case, that unless one of the conductors of a section is cutting flux under a south pole at the same time that the other armature conductor of the same section is cutting flux under a north pole, either the coil will not be working at maximum efficiency (in which case only one conductor will be cutting flux), or both armature conductors will be under poles of like polarity at the same instant so that the e. m. f. generated in one will tend to equalize that in the other. Hence, in practice, we have one conductor of an element under a south pole at the instant that the other is under a north pole, in which case the e. m. f.'s generated by the two coils are additive. It is also universal to have the step or spacing from one armature conductor to the next of that section, nearly equal to the distance between the centers of adjacent unlike poles; but windings could be devised in which the step so made from one conductor to the next would be to the region of a more distant pole; in that case, however, the end connections would be unduly long.

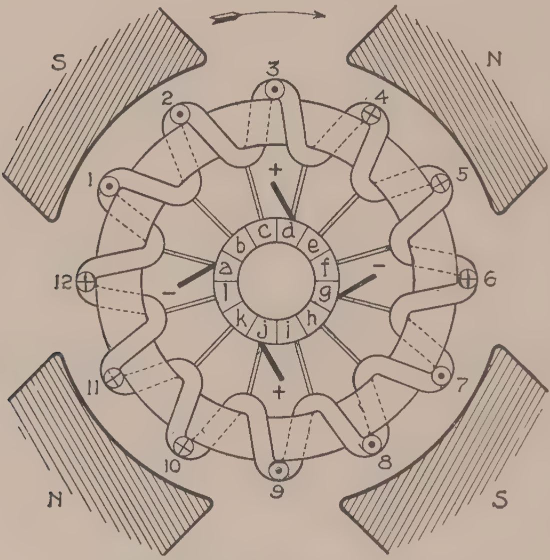


Fig. 119. Ring Winding for 4-Pole Machine.

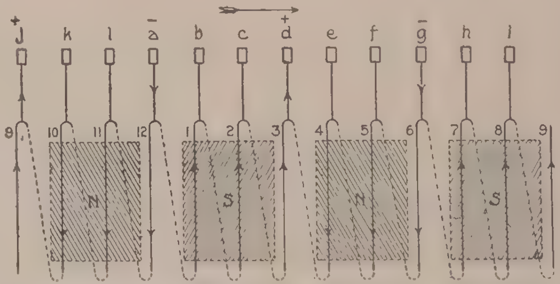


Fig. 120. Development of Ring Winding for 4-Pole Machine.

Pitch of Winding. The pitch or spacing of a winding denotes the distance from one inductor of the winding to the next inductor in the succession; and it is usual to express it in terms of the number of inductors spanned over. In order to see more clearly what

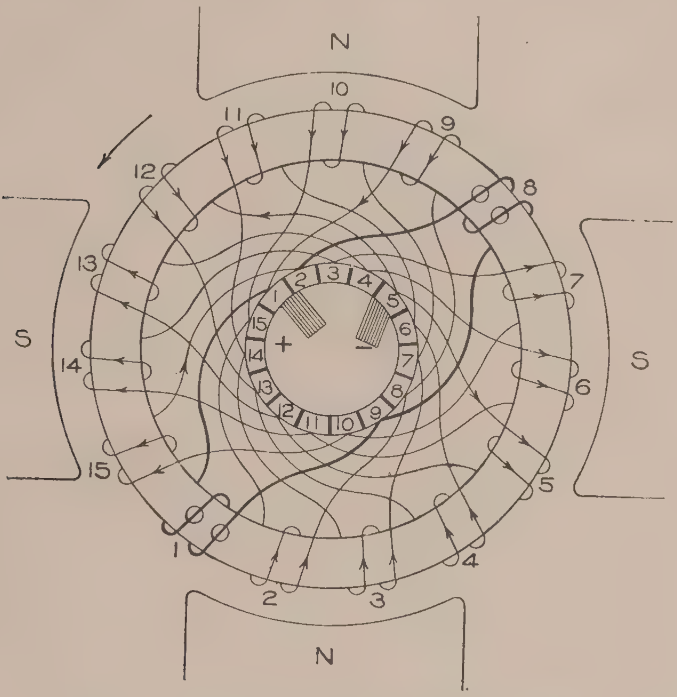


Fig. 121. Series-Connected Wave-Wound Ring Armature.

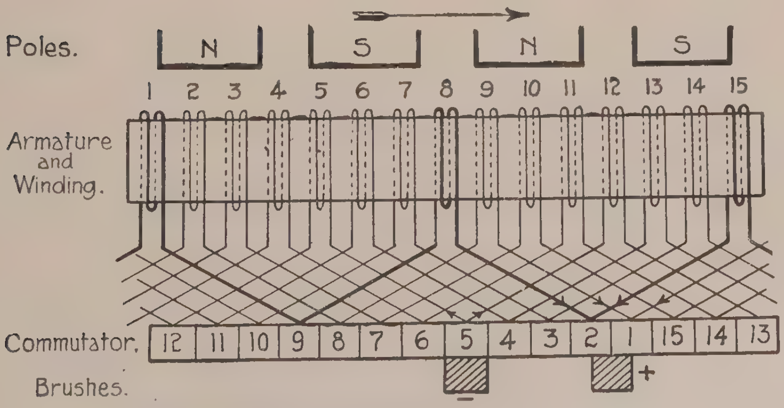


Fig. 122. Development of Winding Shown in Fig. 121.

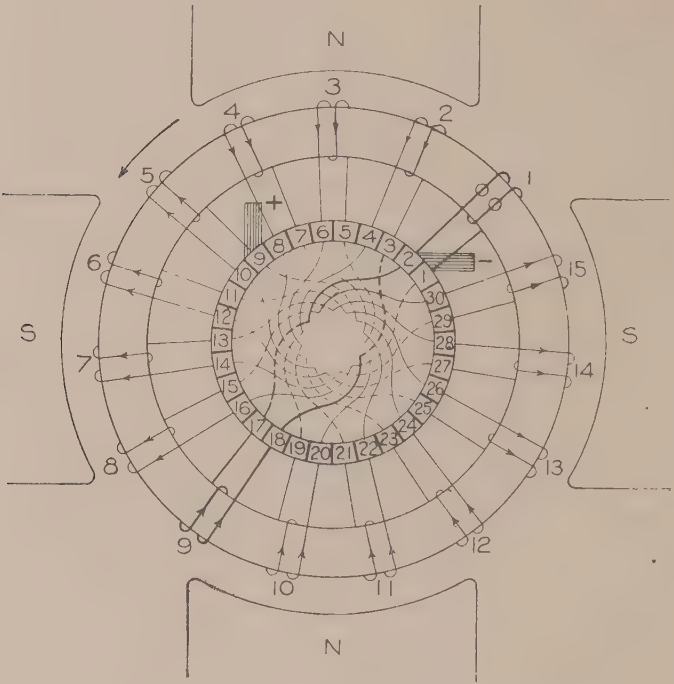


Fig. 123. Series-Connected Multipolar Ring Armature.

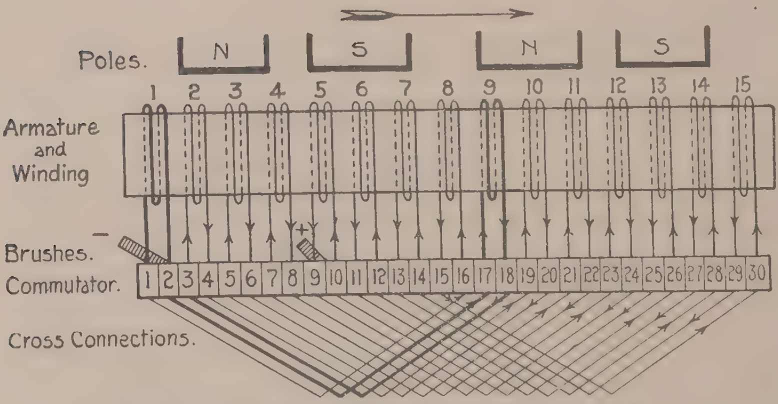


Fig. 124. Development of Winding Shown in Fig. 123.

is meant, let us suppose that the inductors around a certain drum winding are numbered consecutively from 1 up. If it is further assumed that inductor 1 is joined at the front end to inductor 16 to form a loop, and that 16 is joined at the rear to 31 to form a similar loop, the pitch at both ends would be 15. Had 1 been joined to 18 at the front end, and 18 to 3 at the rear end, then 3 to 19 at the front end, the front pitch would be $y_f = +17$, the back pitch $y_b = -15$, the average pitch 16, and the resultant pitch 2.

Ring Windings. Ring windings may be divided into two classes; the *spirally wound* ring, shown in Figs. 119 and 120, and the *series-connected wave-wound* ring, shown in Figs. 121, 122, 123, and 124 for two methods.

The first type, forming in itself a single closed helix, is unaffected by the number of poles; by merely placing $2p$ sets of brushes on the surface of the commutator at equal distances apart, the winding is at once divided into as many equal and symmetrical paths through the armature, and we have $c = p$. A multipolar armature is thus obtained, having as many parallel circuits and as many points of collection of the current as there are poles. The equation of the e. m. f. of such a *multipolar parallel-wound* or *multiple-circuit* armature is similar to that for a bipolar machine; that is,

$$E = \frac{Z \times p\,\phi \times \text{r. p. m.}}{60 \times 10^8 \times c} = \frac{Z \times \phi \times \text{r. p. m.}}{60 \times 10^8},$$

since $c = p$. This multipolar winding has greater current-carrying capacity than the bipolar, since there are more paths in parallel, the multipolar winding being therefore equivalent to several bipolar dynamos in parallel, just as the bipolar machine was shown to be equivalent to two sets of cells in parallel (Fig. 48).

As in a bipolar machine, there are two points on the commutator where the e. m. f. is zero—*i.e.*, where proper commutation may occur—so there will be p points in a multipolar parallel-connected ring winding where the current is commutated, and p brushes will be needed. If, however, the increased number of points of collection be regarded as a disadvantage, they may again be reduced to two, by joining all commutator bars which are situated $360 \div \frac{p}{2}$ degrees apart, so that sectors which are at any moment at the same voltage are connected together. Thus, in a four-pole machine, each commutator bar must be connected to that which is diametrically opposite, and there is a choice between two positions for the brushes at right angles to one another. In a six-pole machine, each cross-connection must unite three sectors situated 120° apart, and the brushes may be either 60° or 180° apart; in an eight-pole machine, four sectors 90° apart must be joined, and the brushes may be either 45° or 135° apart. Thus we see that in general the angle between the brushes of unlike sign may be $180^\circ \div \frac{p}{2}$ or any uneven multiple of this angle. The commutator connections for a four-pole cross-connected winding of the type described, are shown in Fig. 125, while Fig. 126 illustrates the same for a six-pole machine. When thus cross-connected, the commutator must be made $p \div 2$ times as long as before, in order to provide sufficient surface of contact to collect the current by the two sets of brushes; also, the number of commutator segments must be divisible by p.

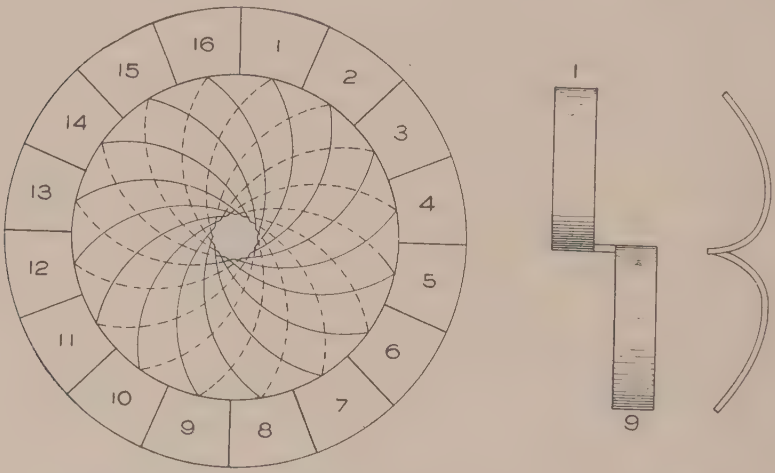


Fig. 125. Commutator Connections for a 4-Pole Cross-Connected Winding.

In the multipolar ring winding of Fig. 119, each pole corresponded to one circuit through the armature, the total number of circuits being therefore equal to the number of poles. It is also possible to add together the inductive effects of two or more poles, so that the e. m. f.'s produced by one-half the inductors on the armature are summed up in series. The winding will then have two paths in parallel, whatever the number of poles. This is called a *series-wound* or *two-circuit* armature. Ring windings of this kind are not used in practice, so that they need not be further considered. Series-wound or two-circuit drum windings are of practical importance, and will be described later.

Forms of Drum Windings. Closed-coil drum windings are of two forms, known as *lap windings* and *wave windings* respectively, and so called from the manner of connecting the ends of the inductors to form a section. In the bipolar type, there is no essential difference between the two forms; but when applied to multipolar machines, the divergence is marked.

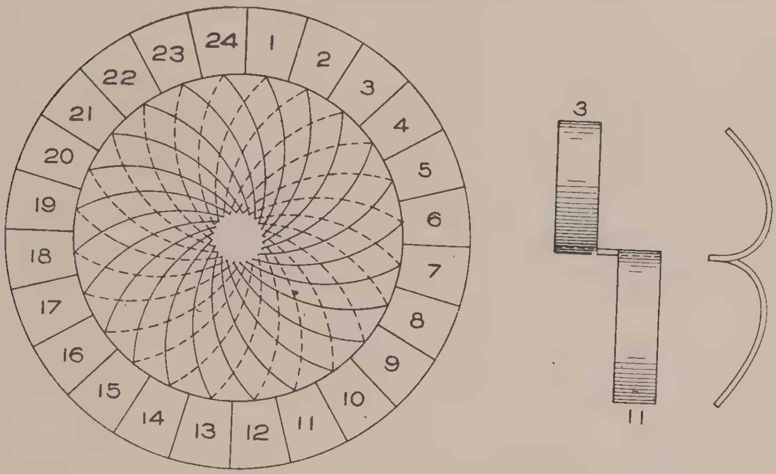
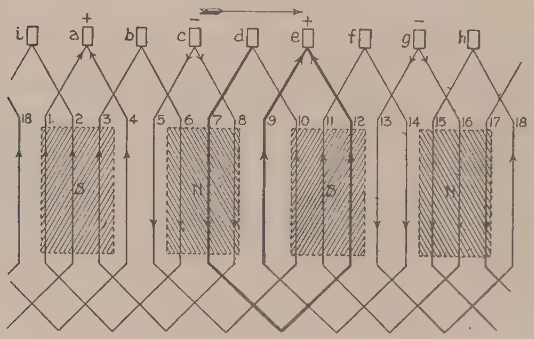


Fig. 126. Commutator Connections for a 6-Pole Cross-Connected Winding.

A simple (simplex) lap winding, Fig. 127, gives as many circuits through the armature as there are poles, whence it is similar to a parallel-wound ring armature. On the other hand, a simplex wave winding, Fig. 128, always gives 2 paths through the armature, irrespective of the number of poles.

It is seen, therefore, from the fundamental formula for the e. m. f. of a dynamo (page 62), that, for a given number of armature inductors, a wave winding will give more voltage than a lap winding in a multipolar field. The latter, however, will give a greater number of paths in parallel through the armature, thus increasing its current capacity.

The distinction between the two windings arises in the following manner. Since the inductors that are passing a north pole generate an e. m. f. in one direction, and those passing a south pole are generating an e. m. f. in the opposite direction, it is clear that an inductor in one of these groups should be connected to one in a nearly corresponding position in one of the other groups, so that the current may flow down one and up the other in agreement with the directions of the e. m. f.'s. If, now, we examine Fig. 127, we see that at the back of the armature—that is, the end distant from the commutator—each inductor is connected with the one five spaces further on, or the pitch at the back is 5. At the front end of the winding, after winding one element—as, for instance, *e*–9–14–*f*—a second element *f*–11–16–*g* is formed, which laps over the first; and so on completely around the winding. In the wave winding illustrated in Fig. 128, however, the case is different. The connections at the rear end remain as in the preceding winding; but at the commutator end, instead of lapping back toward the point from which it started, the connection turns the other way—as, for example, *c*–5–10–*h*. This results in a winding that advances in a sort of zigzag path; hence its name.



F		B	F
+ a	1	6	b
b	3	8	c
− c	5	10	d
d	7	12	e
+ e	9	14	f
f	11	16	g
− g	13	18	h
h	15	2	i
i	17	4	a

Fig. 127. Typical Simplex Lap Winding, and Winding Table for Same.

Lap Windings. Fig. 127 illustrates a simplex or single lap winding, since the terminals of an element are connected to adjacent commutator bars. Following through this winding and starting at segment *a*, we pass along conductor 1 to the rear of the armature, then by an end connection skip over to conductor 6, which leads to commutator bar *b*. From that point, conductor 3 leads again to the rear, and is there connected to 8, which brings us back to bar *c*. Following on in this manner to bar *i* by conductor 2, and from here *via* conductor 17, we finally reach bar *a* through 4, thus closing the winding on itself without traversing each conductor more than once. Calling the interval between the conductors connected at the rear of the armature the *back pitch* (y_b), and the interval between those connected together at the front end the *front pitch* (y_f), we see that for this winding, $y_b = +5$; and $y_f = -3$. The average pitch, being half the arithmetical sum of the front and back pitches, is $y_{av} = 4$; while the resultant pitch is $y_r = +2$, being the algebraic sum of the front and back pitches.

Considering only the case in which each element or section of the winding is a single loop, the number of such sections will be Z ÷ 2; the number of sections (which is the same as the number of resultant steps if multiplied by the length of each resultant step) will equal the total travel of the winding. This will be equal to *Z* if the whole winding must be traversed before closing upon itself. If, however, only one-half or one-third of the winding had to be traversed before the start was reached, the total travel would be *UZ*, where *U* is the number of times the winding must be traversed before finally closing on itself. We have, therefore, for the first condition controlling a lap winding,

$$\frac{Z}{2}(y_b + y_f) = U\,Z; \text{ so that } U = \frac{y_b + y_f}{2},$$

where *U* may be any whole number. Hence it follows that the sum of the front and back pitches must in every case be an even number.

There is also the condition that no conductor shall be encountered twice; that is, no number of steps whatever, however often repeated, shall make $y_b + y_f$ equal to y_f. Or, taking *m* as any whole number,

$$y_f \gtrless m\,(y_f + y_b);$$

whence,

$$y_f \div y_b \gtrless m \div (1-m).$$

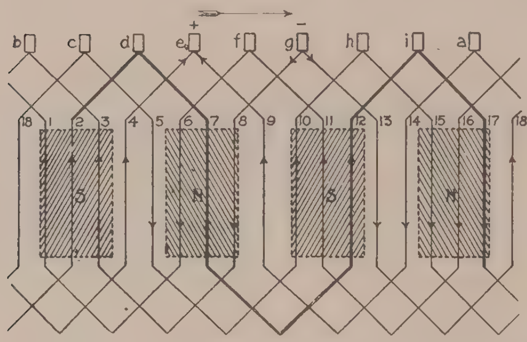
It follows from this inequality, that y_f and y_b cannot possibly have any common factor; and as their difference must be even, it is evident that both must be odd numbers. Also, to make the winding lap back, it is necessary that one of them should be a negative number.

Wave Windings. The winding illustrated in Fig. 128 is called a *simplex wave winding*. Starting at bar *a*, we pass along conductor 1 to the back of the armature, thence by a connector to conductor 6, and then ahead to bar *f*. From here we follow along conductor 11, and then 16 to *b*, whence we are led along 3 and 8 to *g*. Following through the complete winding, we arrive at bar *a* by way of conductor 14, after having traversed each conductor once. Thus the winding closes upon itself after passing through $p \div 2$ winding elements.

For this winding, then, we have,

$$y_f = +5; \ y_b = +5; \ y_{av} = 5; \ y_r = +10.$$

The resultant step is $y_f + y_b$ as before; and the number of such steps being $Z \div 2$, and the total travel through the winding being U, we have;



F		B	F
a	1	6	f
f	11	16	b
b	3	8	g
− g	13	18	c
c	5	10	h
h	15	2	d
d	7	12	i
i	17	4	e
+ e	9	14	a

Fig. 128. Typical Simplex Wave Winding, and Winding Table for Same.

$$\frac{Z}{2}(y_f + y_b) = U\,Z; \quad \text{whence} \quad U = \frac{y_f + y_b}{2}.$$

In order that no conductor be encountered twice in traversing the winding, it must not be possible, by any number of repetitions of the step $y_f + y_b$, to recur to the step y_f beyond any previous number of repetitions of the resultant step. Hence, if m and n are any whole numbers, $m\,(y_f + y_b)$ must not equal $n\,(y_f + y_b)$ steps plus y_f. That is,

$$m\,(y_f + y_b) \gtrless n\,(y_f + y_b) + y_f.$$

It follows in this case, also, that y_f and y_b cannot have any common factor; and as their sum must be even, both of them may be odd, since U may be any number. They may, however, be equal to one another, and this is commonly the case.

General Formulæ for Drum Windings. In general, if y stands for the complete step from the first conductor of any group to the first conductor of the next group, m for the field step, and G for the total number of groups in the winding, we shall have, from the previous deductions:

$$mZ = mgG = \frac{1}{2}\,p\,y \pm c\,,$$

when

$$Z = \frac{p\,y \pm 2\,c}{2m}\,;\ \text{and}\ y = \frac{2\,m\,Z \mp 2\,c}{p}\,,$$

which are the general formulæ for symmetrical windings, where g is the number of conductors per group.

For *lap windings* we have $m = 0$, so that,

$$y = \pm\frac{2\,c}{p}\,.$$

We may separate y into two parts y_f and y_b, of which either is negative, and either slightly less than or equal to $Z \div p$, and which differ from one another by $2c \div p$.

In *lap windings* the step of the winding at the commutator is related to the winding pitch by the simple rule:

$$y_k = y \div g.$$

Thus, in a simple winding of this type where $y = 2$, and where each element of the winding is a simple loop of two conductors so that $g = 2$, we would have $y_k = 1$.

For *wave windings*, $m = 1$, so that,

$$y = \frac{2Z \mp 2\,c}{p}\,;$$

and if this complete step is made up of equal front and back pitches, we shall have:

$$y_f = y_b = \frac{Z \mp c}{p}\,.$$

Re-entrancy of Windings. A winding which closes upon itself is called a *closed-coil winding*, as heretofore noted; also, because it re-enters upon itself, it is known as a *re-entrant winding*.

If the *whole* winding must be traversed before the first inductor is reached or re-entered, the winding is said to be *singly re-entrant*. If one-half the winding need be traversed before the inductor from which the start is made is again encountered, the winding is said to be *doubly re-entrant;* and so on for triply and other multiply re-entrant windings. The number of times the drum is passed *around* is of no consequence when considering the re-entrancy of a drum winding. For example, in Fig. 129, the drum is passed around 25 times before the conductor from which the start is made is reached, yet the winding is singly re-entrant, as shown by the winding table accompanying it.

Multiplex Windings. An armature may be wound with two or more independent windings, each of which may be singly re-entrant, as shown in Fig. 130. These two windings might be furnished with two independent commutators situated at each end of the armature; but usually there is one with the number of its segments doubled, the two sets of bars being alternated between one another. In this case the brushes must be made broad enough to overlap at least two and one-half commutator bars, so as to collect current from both windings simultaneously. Such a winding is known as a *duplex singly re-entrant winding*. *Triplex-wound armatures* have three independent windings, with three sets of commutator bars similarly arranged.

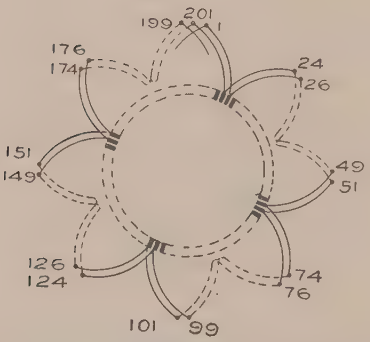


Fig. 129. Wave Winding, 8-Pole, 2-Circuit, Singly Re-entrant. (See Winding Table on Page 107.)

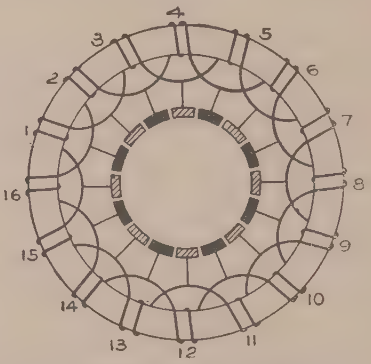


Fig. 130. Duplex Winding Consisting of Two Singly Re-entrant Ring Windings.

The advantage of multiplex windings is that sparking at the brushes may be considerably lessened, for the coils are short-circuited a much shorter length of time and there is a longer brush-resistance path. Hence multiplex windings are much used in machines intended to supply large currents at small voltages, such as generators for electrolytic work.

WINDING TABLE FOR 8-POLE DRUM ARMATURE; 202 CONDUCTORS; TWO-CIRCUIT, SERIES-PARALLEL GROUPING; BRUSHES (±) 135° APART.

F	B	F	B	F	B	F	B	F

D	U	D	U	D	U	D	U
1	26	51	76	101	126	151	176
201	24	49	74	99	124	149	174
199	22	47	72	97	122	147	172
197	20	45	70	95	120	145	170
195	18	43	68	93	118	143	168
193	16	41	66	91	116	141	166
191	14	39	64	89	114	139	164
189	12	37	62	87	112	137	162
187	10	35	60	85	110	135	160
185	8	33	58	83	108	133	158
183	6	31	56	81	106	131	156
181	4	29	54	79	104	129	154
179	2	27	52	77	102	127	152
177	202	25	50	75	100	125	150
175	200	23	48	73	98	123	148
173	198	21	46	71	96	121	146
171	196	19	44	69	94	119	144
169	194	17	42	67	92	117	142
167	192	15	40	65	90	115	140
165	190	13	38	63	88	113	138
163	188	11	36	61	86	111	136
161	186	9	34	59	84	109	134
159	184	7	32	57	82	107	132
157	182	5	30	55	80	105	130
155	180	3	28	53	78	103	128
153	178	1					

Paths in Parallel and Conductors in Series between Brushes. In a simplex lap winding there will be p paths in parallel between the brushes, and $Z \div p$ conductors in series. In a simplex wave winding, there will always be 2 paths in parallel through the armature, and each path will consist of $Z \div 2$ conductors in series.

A multipolar lap winding is often called a *parallel-grouped winding,* on account of the number of parallel paths through the armature. Sometimes it is called a *multiple-circuit winding* for the same reason. Similarly, a simplex wave winding is called either a *two-circuit winding* or a *series winding.*

Combining simplex windings to give a multiplex winding adds to the number of paths in parallel through the armature, but not the generated e. m. f. The latter is increased by multiplying the number of turns per coil, or the number of coils in series; but having a great number of turns per section (that is, element of the winding) aggravates the tendency to spark, as already shown (page 46).

Number of Brush Sets Required. Where there are p points around the commutator at which the voltage is zero (see page 35 for method of measuring potential around a commutator), p sets of brushes may be used in any case. In a lap winding, simplex or multiplex, p sets must be used in order to collect the full armature current; while in wave windings, simplex or multiplex, 2 sets of brushes are sufficient, though any number up to p may be used in order to insure sparkless collection of the armature current. For, by referring to Fig. 131, it is seen that if six brushes were placed around the commutator 60 degrees apart, the extra ones might be considered as cross-connections introduced to reduce the armature I^2R loss.

Conditions to be Satisfied by a Closed-Coil Drum Winding. A drum winding cannot have an odd number of inductors. Both the front and back pitches must be odd in simplex windings, for the odd-numbered conductors may be regarded as the returns for even-numbered ones.

Both the front and back pitches must be approximately equal to $Z \div p$, in order that conductors moving simultaneously under poles of opposite polarity should have their generated e. m. f.'s additive. The smallest pitch meeting this condition would stretch completely across a pole-face, while the largest would stretch from the given pole-tip to the next pole-tip of like polarity. When the front and back pitches differ considerably from $Z \div p$, the winding is called a *chord winding*, the name being due to the appearance of the end-connections. As we have seen, this method possesses the advantage of cutting down the demagnetizing effect of the armature; but it has the disadvantage that the two edges of any section are not both passing at the same time into a commutating field, so that it is not suitable for handling large outputs of current.

For a given number of inductors, the front and back pitches must be chosen so as to comply with the following conditions:

(*a*) All winding elements must be similar mechanically and electrically, and must be symmetrically placed upon the armature.

(*b*) In a simplex winding, every inductor must be passed over once only, and the winding must close upon itself, or be re-entrant.

(*c*) In a multiplex winding, each simplex element must comply with condition (*b*).

(*d*) A multiplex winding not consisting of complete and independent simplex windings (called a *singly re-entrant multiplex winding*), must as a whole satisfy condition (*b*).

(*e*) In a *two-layer winding* (that is, one where the conductors are placed one on top of another in a slot), it is usual to give the upper ones odd numbers, and the lower ones even numbers.

In addition to these conditions for drum windings in general, lap windings must also comply with the following:

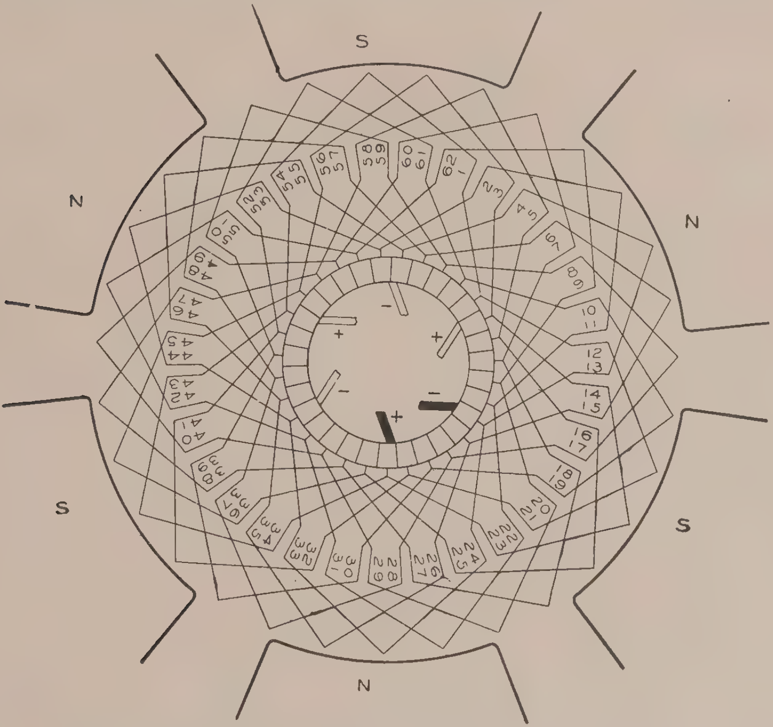


Fig. 131. Six-Pole Drum Simplex Wave Winding, Singly Re-entrant.

(*a*) Front and back pitches must be opposite in sign.

(*b*) The front and back pitches must be unequal, otherwise the coil would be short-circuited upon itself.

(*c*) In a simplex lap winding, the front and back pitches differ by 2; that is $y_b = y_f \pm 2$.

(*d*) In a multiplex lap winding, the front and back pitches differ by $2x$, where x is the number of component simplex windings.

(*e*) Z may be any even number; and in slotted armatures, it must also be a multiple of the number of slots; the latter may be even or odd.

Wave windings must similarly comply with the following conditions:

(*a*) Front and back pitches must be alike in sign.

(*b*) Front and back pitches may be equal, or differ by any multiple of two. Usually they are both equal nearly to $Z \div p$, although one may be less, and the other greater.

(*c*) In simplex windings, $Z = p\,y_{av} \pm 2$.

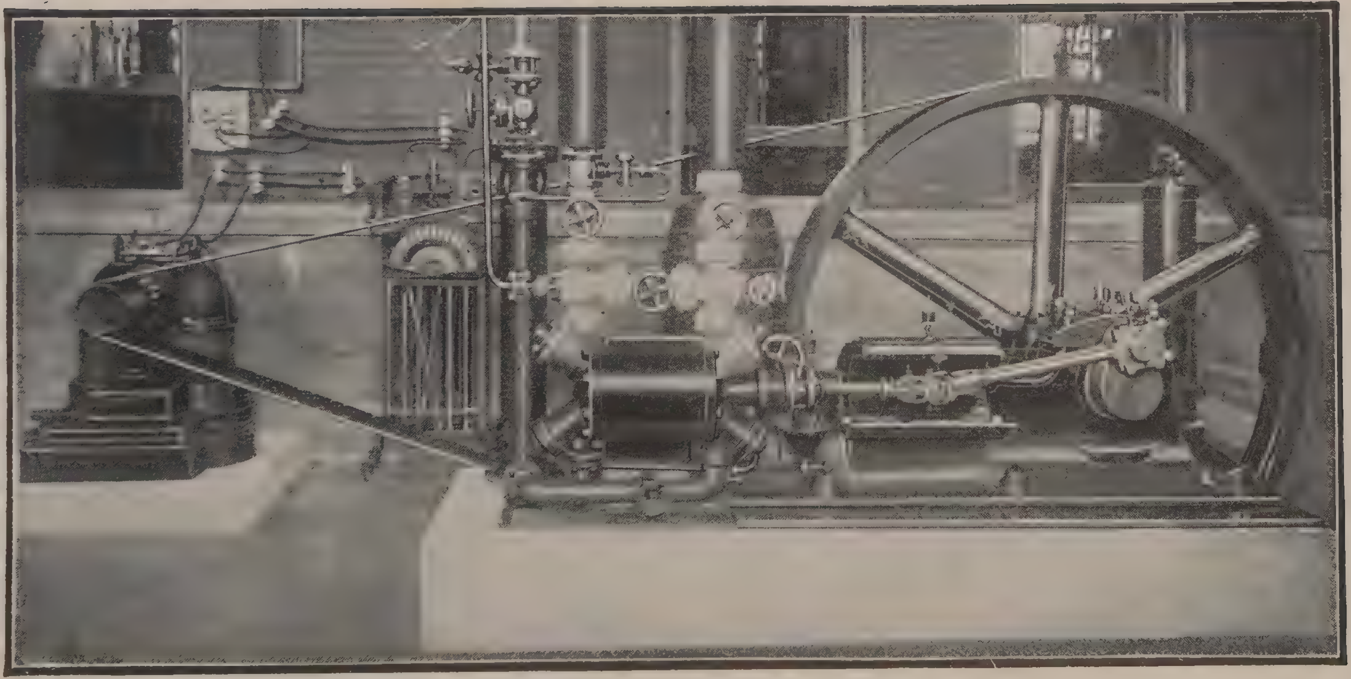
(*d*) In multiplex windings, $Z = p\,y_{av} \pm 2x$.

Resumé of Winding Formulæ. In Table VI will be found formulæ covering most of the types of ring and drum windings which are now used. The symbols in the columns have the same significance as those used in the text.

Equipotential Connections. As the armature in practice is not always centered exactly with respect to the pole-pieces—and, further, since the conductors are not equidistant from the latter, because of winding inequalities—the generated e. m. f. of the various sections will not be exactly equal. Hence there will be cross-currents internal to the armature, which increase sparking at the commutator and heating of the armature. In wave windings, the conductors are connected in series and so distributed as to have no perceptible tendency to produce cross-currents; but in lap windings, inaccurate centering may lead to the production of large local currents. In order to reduce their production as much as possible, it is customary, in large generators or in others liable to be so affected, to connect through low-resistance leads, the bars, or conductors at the same voltage. These connections are called *equipotential connections;* and although they reduce the sparking tendency due to local currents in the armature, they add a little to the heating of the armature.

Examples of Armature Windings. On the following pages will be found examples of windings in common use. In Figs. 131 to 137 inclusive, the short, radial, numbered lines represent the conductors; the crossed lines outside of the circle of conductors represent the connections at the back end of the armature; and the crossed lines between the circle of conductors and the commutator at the center, represent the connections at the front end of the armature. For the sake of simplicity, only a few conductors are shown in these examples; and it should be noted that in actual designs, their number Z attains a much greater value.

Fig. 132 represents a six-pole drum simplex singly re-entrant lap winding, with 60 conductors, a front pitch of –11, and a back pitch of + 9. In this particular case the general progression of the



12-TON LINDE REFRIGERATING MACHINE.

Operated by an Electric Motor.

Fred W. Wolf Company.

winding is around the drum in an anti-clockwise direction, and on this account it is sometimes called a *retrogressive* winding to distinguish it from a clockwise one, which is called a *progressive* winding. The winding here shown has a commutator pitch of –1, and there are six paths in parallel through the armature, necessitating six brush sets unless the winding or commutator is cross-connected (see Fig. 125).

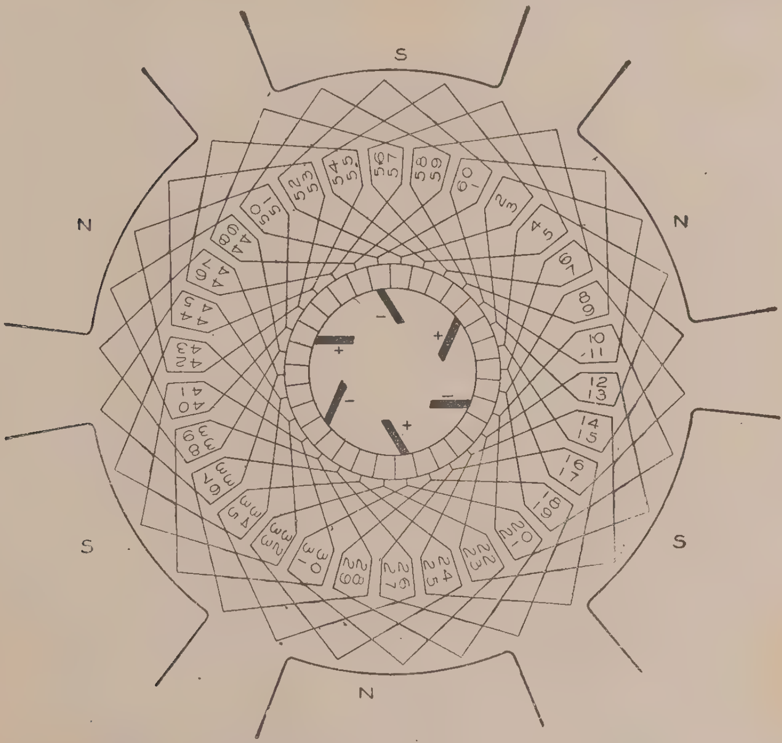


Fig. 132. Six-Pole Drum Simplex Lap Winding, Singly Re-entrant.

Fig. 131 illustrates a six-pole drum simplex singly re-entrant wave winding of 62 inductors. It has a front pitch of +11, and a back pitch of +9, giving an average pitch of 10, and a commutator pitch of 10 also. This winding has two paths in parallel through the armature, so that only two brush sets are required. The locations of the other brush sets, which may be added if large currents are to be collected, are also indicated by dotted lines.

Fig. 133 shows a six-pole drum duplex doubly re-entrant lap winding composed of 60 inductors with a front pitch of –11, a back

TABLE VI

Formulæ for Ring and Drum Windings

RING WINDINGS

Types of Winding	No. Circuits in Parallel through Arm. $= c$	No. Circuits in Parallel per Winding $= c_1$	No. Separate Windings $= x$	Field Step $= m$	No. Conductors $= Z$	Resultant Pitch $= y$	Commutator Pitch $= y_k$	Conductors in Series between Brushes	No. Brush Sets	Angle between Brush Sets	Figs. Illustrating Winding
A*	ϕ	ϕ	1	0	$= g\,G = g\,K$	$\pm g$	$\pm g$	$Z \div p$	p	$360° \div p$	....
B	2	2	1	1	$= \frac{g\,p\,y \pm 2}{2}$ and $= g\,G = g\,K$	$\frac{2\,Z \mp 2}{p}$ and must be odd	$\frac{2\,K \mp 2}{p}$	$Z \div 2$	Min. 2 Max. p	$360° \div p$ or any odd multiple	....
C	4, 6, 8, or any other even number > 2	c	1	1	$\frac{p\,y \pm c}{2}$	$\frac{2\,Z \mp c}{2}$	$\frac{2\,K \mp c}{p}$	$Z \div c$	p	$360° \div p$	....
D	$x\,p$	p	2, 3, 4, or any other whole number	0	$= x\,g\,b = x\,g\,k$	$\pm g\,x$	$\pm g\,x$	$Z \div x\,p$	p	$360° \div p$	....
E	$2\,x$	2	do	1	$\frac{g\,n\,p\,y \pm 2\,n}{2}$	$\frac{2\,Z \mp 2\,x}{x\,p}$	$\frac{2\,K \mp 2\,x}{p}$	$Z \div 2\,x$	Max. p Min. 2	$360° \div p$ or any odd multiple	....
F	$x\,c_1$	4, 6, 8, or any other even number > 2	do	1	$\frac{g\,n\,p\,y \pm 2\,n\,c_1}{2}$	$\frac{2\,Z \mp 2\,x\,c_1}{x\,p}$	$\frac{2\,K \mp 2\,x\,c_1}{x\,p}$	$Z \div x\,c_1$	p	$360° \div p$	....

LAP-WOUND DRUM WINDINGS

Types of Winding	No. Circuits in Parallel through Arm. $= c$	No. Conductors in Series between Brushes	No. Separate Windings $= x$	No. Circuits in Parallel per Winding $= c_1$	Field Step $= m$	No. Armature Conductors $= Z$	Resultant Pitch $= y$	Forward Pitch $= y_f$	Backward Pitch $= y_b$	Commutator Pitch $= y_k$	No. Brush Sets	Angle between Brush Sets	Figs. Illustrating Winding
G*	p	$Z \div p$	1	p	0	$Z = 2\,g\,G = 2\,g\,Z$, *i. e.*, any even number	± 2	Equal to or less than $\frac{Z}{p}$, and must be odd	$-(y_f \pm 2)$	1	p	$360° \div p$	132
H	$p\,x$	$Z \div p\,x$	2, 3, 4, or any other whole number	p	0		$\pm 2\,x$		$y_f - 2\,x$	$\pm x$	p	$360° \div p$	....
J	4, 6, 8, or any other even number > 2	$Z \div c$	1	4, 6, 8, or any other even number > 2	0		$\pm c$		$y_f - c$	$\pm \frac{1}{2}\,c$	ϕ	$360° \div p$	135
K	$x\,c_1$	$Z \div x\,c_1$	2, 3, 4, or any other whole number	do x p	0		$\pm x\,c_1$		$y_f - x\,c_1$	$\pm \frac{1}{2}\,x\,c_1$	p	$360° \div p$	133

WAVE-WOUND DRUM WINDINGS

TYPES OF WINDING	NO. CIRCUITS IN PARALLEL THROUGH ARM. $= c$	NO. CONDUCTORS IN SERIES BETWEEN BRUSHES	NO. SEPARATE WINDINGS $= x$	NO. CIRCUITS IN PARALLEL PER WINDING $= c_1$	FIELD STEP $= m$	NO. CONDUCTORS $= Z$	$y_f = y_b$	COMMUTATOR PITCH $= y_k$	NO. BRUSH SETS	ANGLE BETWEEN BRUSH SETS	FIGS. ILLUSTRATING WINDING
L*	2	$Z \div 2$	1	2	1	$p\, y_{av} \pm 2$	$\frac{Z \mp 2}{p}$ must be odd and have no common factor with Z	$\frac{2K \mp 2}{p}$	Min. 2 Max. p	$360° \div p$, or any odd multiple	132
M	$x\, c_1$	$Z \div x\, c_1$	2, 3, 4, or any other whole number	2	1	$x\, p\, y_{av} \pm 2\, x$	$\frac{Z \mp 2x}{x\, p}$ where y_{av} is even y_f may $= y_{av} + 1$ y_b may $= y_{av} - 1$	$\frac{2K \mp 2x}{x\, p}$	Min. 2 Max. p		137
N	4, 6, or any other even number > 2	$Z \div c$	1	4, 6, 8, or any other even number > 2	1	$p\, y_{av} \pm c$	$\frac{Z \mp c}{p}$	$\frac{2K \mp c}{p}$	Min. 2 Max. p		136
P	$x\, c_1$	$Z \div x\, c_1$	2, 3, 4, or any other whole number	2, 4, 6, or any other even number	1	$x\, p\, y_{av} \pm x\, c_1$	$\frac{Z \mp x\, c_1}{x\, p}$	$\frac{2K \mp x\, c_1}{x\, p}$	Min. 2 Max. p		134

* Key to Special Types of Ring, Lap, and Wave Windings is given below:

KEY TO TABLE VI

Following is a key to the special types of Ring, Lap, and Wave Windings for which formulæ are given in Table VI:

RING WINDINGS

A—Parallel Grouping (Simplex).
B—Series Grouping (Singly Re-entrant).
C—Series-Parallel Grouping (Simplex Doubly or Multiply Re-entrant).
D—Duplex or Multiplex Parallel Grouping.
E—Duplex or Multiplex Series Grouping.
F—Duplex or Multiplex Series-Parallel Grouping.

LAP-WOUND DRUM WINDINGS

G—Simplex Singly Re-entrant (Parallel) Lap Winding.
H—Duplex or Multiplex (Parallel) Lap Winding.
J—Simplex (Series-Parallel) Doubly or Multiply Re-entrant Lap Winding.
K—Duplex or Multiplex (Series-Parallel) Doubly or Multiply Re-entrant Lap Winding.

WAVE-WOUND DRUM WINDINGS

L—Simplex Singly Re-entrant (Series) Wave Winding.
M—Duplex or Multiplex (Series) Wave Winding.
N—Simplex Doubly or Multiply Re-entrant (Series-Parallel) Wave Winding.
P—Duplex or Multiplex Doubly or Multiply Re-entrant (Series-Parallel) Wave Winding.

pitch of +7, a commutator pitch of –2, and 12 paths in parallel through the armature. This winding is also retrogressive, and composed of two complete but distinct simplex singly re-entrant lap windings, each having 30 inductors. One set is represented by the full lines, the other by the broken lines, their respective commutator segments being unshaded and shaded. It should be noted that with

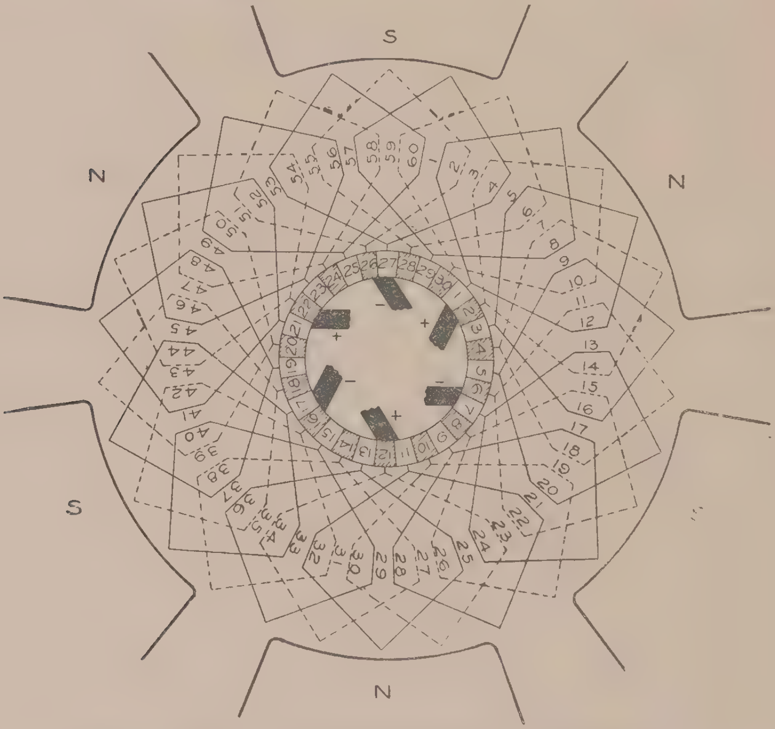


Fig. 133. Six-Pole Drum Duplex Lap Winding, Doubly Re-entrant.

a duplex or any other multiplex winding, the brushes must be wide enough to cover at least as many segments as there are windings. Here the brushes cover two segments.

Fig. 134 represents a six-pole drum duplex doubly re-entrant wave winding, consisting of 64 inductors, having a front pitch of +9, a back pitch of +11, and a commutator pitch of 10. The average pitch is 10, and there are four paths in parallel through the armature. Nevertheless only two brushes are required to collect the current, although others may be added as indicated, if desired. It consists of two complete simplex singly re-entrant wave windings; hence its appellation, *duplex doubly re-entrant.*

Fig. 135 represents a four-pole drum simplex doubly re-entrant lap winding having 34 inductors. In this case the front pitch is +9, the back pitch is –5, and the commutator pitch is +2, while there are 8 paths in parallel through the armature. Four brushes only are required, and inspection shows this to be a progressive winding.

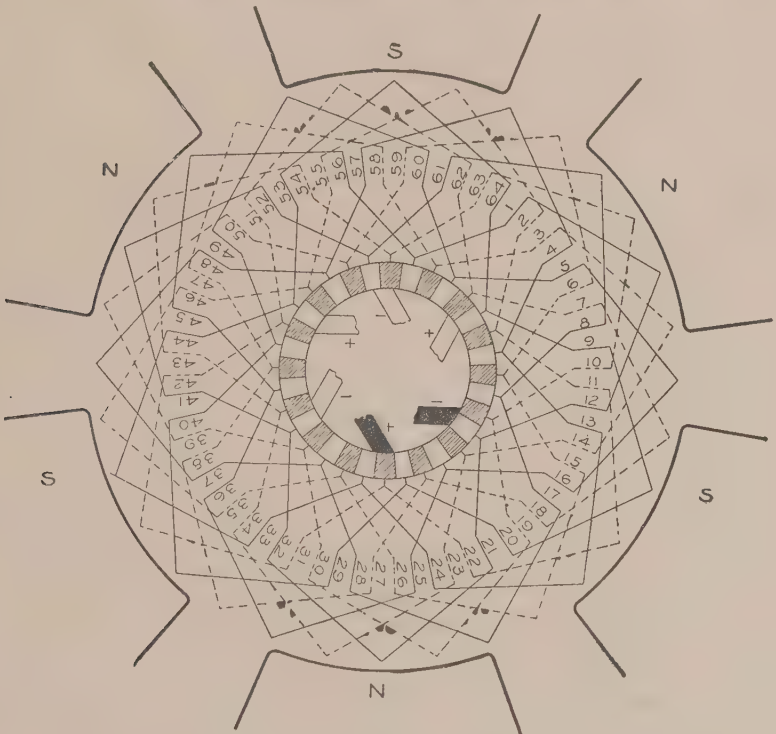


Fig. 134. Six-Pole Drum Duplex Wave Winding, Doubly Re-entrant.

Fig. 136 illustrates a four-pole drum simplex trebly re-entrant wave winding having 34 inductors, with a front pitch of –11 and a back pitch of –9. The commutator pitch is –10, and it is seen that this is a retrogressive winding, having six circuits in parallel through the armature.

In Fig. 137 we have a six-pole drum duplex singly re-entrant wave winding, with a back pitch of 11, a front pitch of 9, an average pitch and a commutator pitch of 10. It has two paths in parallel through the armature; and although only two brushes are required, six sets may be used if desired, as indicated. It is a progressive winding.

Length of Armature Winding. The length of wire in an armature winding depends upon the particular type of winding employed. Determination of this length is necessary in the design of dynamo-electric machinery in order to compute the armature resistance and the resulting regulation of the machine. G. Simonds,* J. Dalemont,** H. M. Hobart,† and A. I. M. Winetraub†† have given methods for computing the lengths of winding necessitated by the different types; but the method usually employed by manufac-

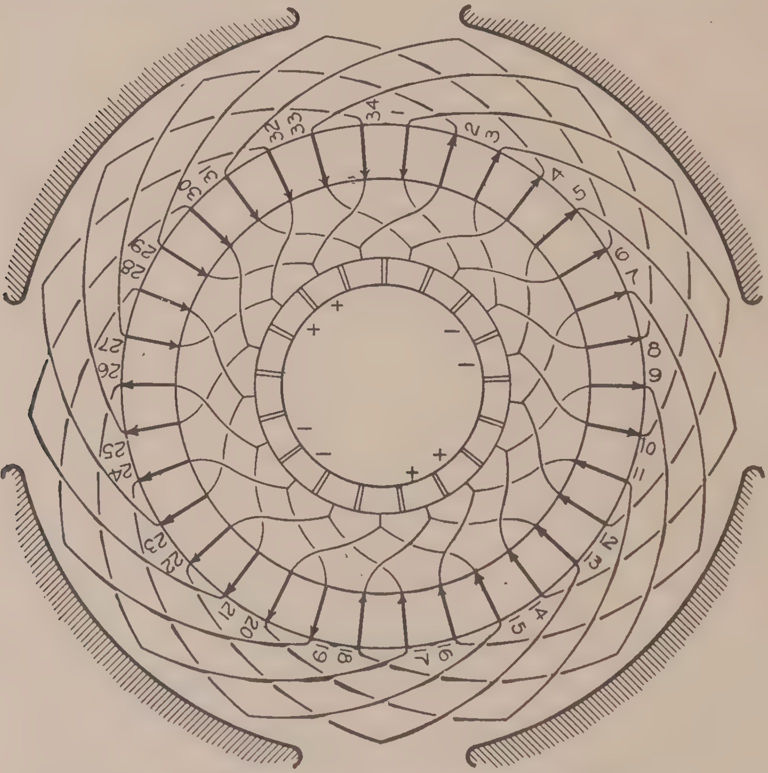


Fig. 135. Drum Simplex Doubly Re-entrant Lap Winding.

**Electrical World*, March 3, 1900.

** Bulletin of the Institute Montefiore, 11, 428, 1902.

† *Traction and Transmission*, V, 239, 1902.

†† *Electrical World*, August 25, 1906.

turers consists simply in drawing the armature to scale, and laying off thereon a section of the winding, the requisite length of wire being then determined by actual measurement. In particularly important cases—for example, when a new type of machine is to be built in large numbers or sizes—a portion of a dummy armature core is made of wood and wound with the correct size of wire. The length thus employed for one section is then multiplied by the number of sections to obtain the total length of wire required.

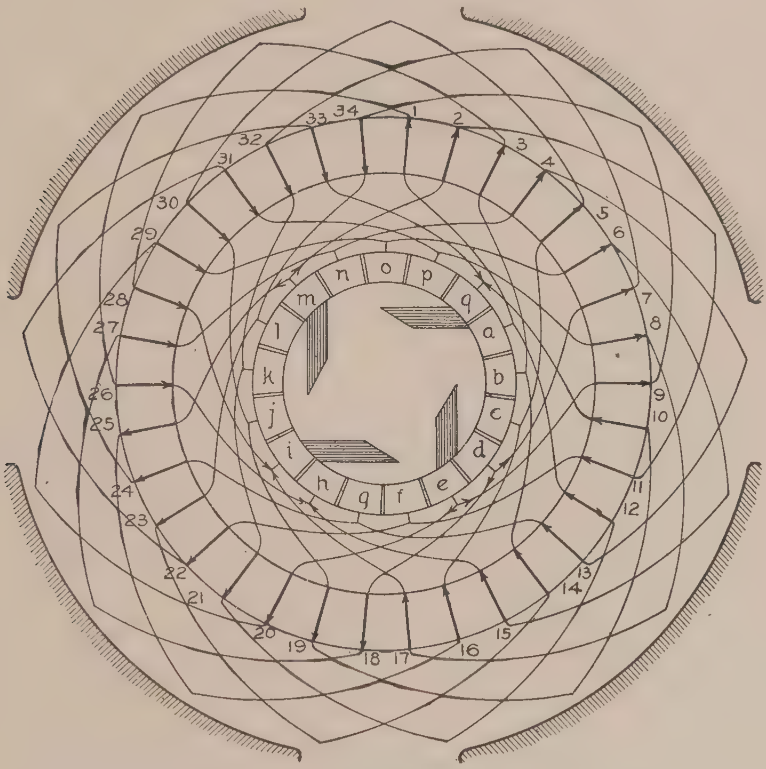


Fig. 136. Six-Circuit Drum Simplex Trebly Re-entrant Wave Winding.

Armature Resistance. Having obtained the length of wire required for the winding, the resistance of the armature may be calculated from the formula,

$$r_a = \frac{\rho\, l}{c^2\, s},$$

wherein ρ is the resistance of a unit-length of copper of unit cross-section; l is the total length of the armature winding in the same linear units as ρ; c represents the number of circuits in parallel through the armature; and s is the cross-sectional area of the conductor in the same units as that upon which the value of ρ is based.

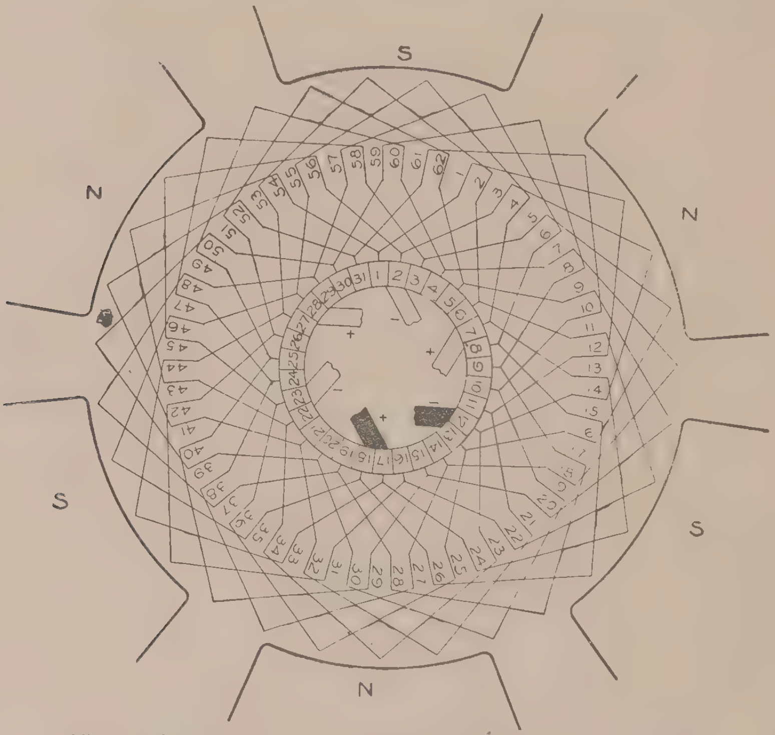


Fig. 137. Six-Pole Drum Duplex Wave Winding, Singly Re-entrant.

A circular conductor one foot long and one mil (0.001 inch) in diameter is called a *circular mil foot;* and if composed of standard copper, it has at 20° Centigrade a resistance of 10.35 ohms, and at 0° Centigrade a resistance of 9.55 ohms. At any other temperature t, the resistance R_t is:

$$R_t = 9.55\,(1 + 0.0042t).$$

If we take as our basis of calculation a square conductor, the cross-section being a square each of whose sides is one mil long, we have a *square mil foot,* which has an area $4 \div \pi$ times that of a circular mil foot. Hence its resistance is $\pi \div 4$, or 0.7854 of that of a circular mil foot. Hence the resistance of a square mil foot of copper wire at 20° C. is 10.35 × 0.7854 = 8.15 ohms, and at 0° C. it is 9.55 × 0.7854 = 7.5 ohms.

The resistance of any copper conductor, the cross-section of which is given in circular mils, is at 20° C. equal to $\frac{10.35 \times l}{d^2}$, where l is the length of the conductor in feet, and d^2 is the cross-section in circular mils (that is, the square of the diameter in mils).

Example. 1,200 feet of copper wire 0.1 inch (100 mils) in diameter is required for a certain six-circuit armature winding. Substituting in the equation $r_a = \frac{\rho\, l}{c^2\, s}$, we have for the resistance of the armature:

$$r_a = \frac{10.35 \times 1{,}200}{36 \times 10{,}000} = 0.0345 \text{ ohm at } 20°\text{C.}$$

Armature Losses. The losses in the armature may be divided into those due to the resistance of its winding, and those due to the hysteresis and eddy currents in its iron core.*

Under the preceding heading, a method of finding the resistance of the armature winding was given; hence the copper loss in the armature due to the resistance of its winding is:

$$w_{cu} = I_a^2\, r_a.$$

For calculating the hysteresis loss w_h in the armature, we may use the formula and curves given on page 14, or may refer to a curve obtained by test upon the iron to be used. Similarly, the eddy-current loss w_e may be computed from the formula given on page 15, or from the graphs of Fig. 17. The total iron loss in the armature is therefore:

$$w_i = w_e + w_h.$$

It is found, however, by tests upon actual machines, that the iron losses thus computed are considerably lower than the true values. This is no doubt due to unequal distribution of flux in the various parts of the magnetic circuit subject to a varying flux-density; also to the departure from the ideal conditions in the matter of dispersion, and to the presence of wasteful currents in other parts of the machine. Prof. J. Epstein† gives curves, Fig. 138, showing that the calculated losses of a machine based on any of the heretofore standard data would be low; hence the actual commercial efficiency is lower than the computed.

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* Windage due to the rotation of the armature will be dealt with under a later heading.

†Proceedings of the Institution of Electrical Engineers of Great Britain, Nov. 11, 1906.

In addition to the calculated iron and copper losses, there may be a loss in the armature conductors due to eddy currents, and another loss if for any reason the current does not distribute itself evenly through the conductor. Also, if the division of current between the parallel circuits of the armature winding is not uniform, and equalizing connections are not provided, an additional loss results. These are so obscure as to baffle computation; and as their value is small, they may be neglected.

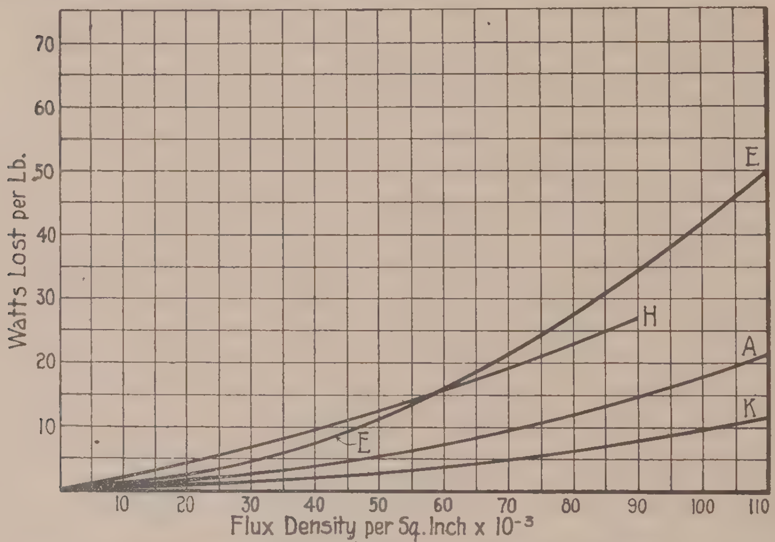

Fig. 138. Standard Iron-Loss Curves at 30 Cycles per Second. *E*—Prof. Epstein; *H*—Hobart, "Electric Motors;" *A*—Prof. Arnold, *Die Gleichstrommaschine*; *K*—G. Kapp, *Gleichstrom und Wechselstrom.*

Heating of Armatures. The amount of heat which will be dissipated by a unit surface of a moving armature depends upon:

(1) Resistance, eddy-current, and hysteresis losses in the armature.

(2) Heat-radiating surface of the armature.

(3) Peripheral speed of the armature.

(4) Proportion, within limits, of the ratio of the radiating surface to polar surface.

(5) Temperature of the radiating surface.

The first of these is dependent upon the internal actions of the armature, and represents the total heat which must be dissipated.

The surface exposed to the cooling action of the air is somewhat indefinite, but in most cases the total peripheral surface of the armature is assumed as radiating surface, and to this may be added one-half the surface of the ends of the armature.

As the peripheral speed of the armature becomes greater, it is found that the radiating capability of its surface increases, though not in direct proportion.

Messrs. A. H. and C. E. Timmerman* found by actual test that the effect of pole-faces above a surface is to interfere with the radiation of heat. As the proportion of surface covered by the pole-faces became larger, the amount of heat radiated per degree rise in temperature became less. They also found that elevation in temperature of a surface caused an increase in the radiation of heat per degree rise in temperature, but that this rate diminished as the temperature rose.

Various formulæ may be given for estimating the ultimate rise in temperature of armatures; but as most of them are empirical and clumsy, the curves of Fig. 139 have been substituted. With their aid, we may determine the temperature-rise in degrees Centigrade of an armature at any usual peripheral speed, if we know the total radiating surface and the total armature losses.

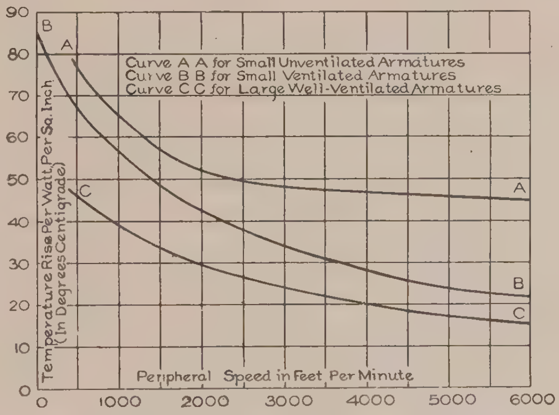

Fig. 139. Curves for Estimating Temperature-Rise.

Example. In a 480-kilowatt generator, the heat-radiating surface of the armature was computed to be about 5,000 square inches, while total losses in the armature were found to be 12,330 watts by calculation. Hence the watts wasted per square inch of heat-radiating surface are 12,330 ÷ 5,000 = 2.46.

As the peripheral speed of the armature in this instance was 4,500 feet per minute, we see by reference to the curves of Fig. 139, that there will be a rise of 19° C. for each watt per square inch. Hence the temperature-rise of this armature will be approximately:

$$\theta_a = 2.46 \times 19 = 47^\circ \text{ C.}$$

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* Transactions of the American Institute of Electrical Engineers, Vol. X, 1893.

Commutator and Brush Calculations. Commutators for continuous-current machines may be divided into two classes, depending upon whether they are for *open* or *closed-coil* armature windings. In the former special case, used for arc-lighting generators, the commutator has a small number of segments separated from each other by an air-gap, and each covering a considerable angle. With closed-coil windings, ordinarily used for direct-current lighting and power, in which case the terminal voltage is kept comparatively constant (in contradistinction to series arc-lighting machines, for which the current is constant), the commutator is of the original Pacinotti type —that is, consisting of a considerable number of parallel bars or segments separated by strips of insulation, usually mica. In both cases the completed commutator presents a cylindrical surface against which the brushes press.

Number of Segments. The number of segments depends upon the number of sections of the winding, as shown on page 95. We have also seen (page 49) that increasing the number of commutator segments reduces the tendency to spark at the brushes. This increase is limited, however, by the matter of cost, and the fact that the number of sections in a drum-wound armature can never exceed one-half the number of inductors, while, in a ring-wound armature, the number of sections can never be greater than the number of inductors.

The proper number of segments is therefore determined by the winding of the armature, which depends upon the voltage and output of the machine. If by experience the suitable number of average volts per segment e_k of the commutator be known, then K, the number of segments, may be readily computed from the following formula:

$$K = E c \div e_k.$$

Experience shows that the values of e_k indicated in Table VII, may be chosen, although the matter is influenced by the current to be collected. If the latter be less than 100 amperes, then the value of e_k may be increased, but in no case should it exceed 25 volts.

Arnold has given the rule that the number of commutator segments must *never be less than* from 0.037 to 0.04 times the product of the number of armature inductors into the square root of the current carried by one circuit of the armature. This rule is an empirical one based on observations with regard to sparking; nevertheless it has been found that good machines were built in which the constant was slightly less than 0.037.

Example. A 1,000-kilowatt generator having 16 paths in parallel through its armature produced 500 volts at its terminals. The number of armature conductors was 2,304. Hence, according to Arnold's rule, K must not be less than $0.037 \times 2{,}304 \sqrt{2{,}000 \div 12} = 956$. As a matter of fact, 1,152 segments were taken for this machine, making the number of segments equal to one-half the number of conductors.

TABLE VII

Voltage and Number of Segments

For Machines Working at	Average Volts per Segment $= e_k$	Average Segments per Pole or Circuit
500 to 650 volts	5 to 12	40 to 150 or more
200 to 250 volts	3 to 8	25 to 75
100 to 130 volts	2 to 4	20 to 50

Size of the Commutator. The size of the commutator depends upon the number of segments, their thickness and that of the insulation between them, and the length of the segments parallel to the shaft. The diameter is limited by the peripheral speed allowable. The length depends upon the amount of current to be collected, a density of 50 amperes per square inch being as much as should be allowed for the contact area between a carbon brush and the bar. Bars are rarely ever thinner than 0.2 in., or with insulation say 0.3 in., and the peripheral speed of a commutator seldom exceeds 2,500 feet per minute; so that by keeping within these limits good results may be expected. A favorite size for commutator diam-

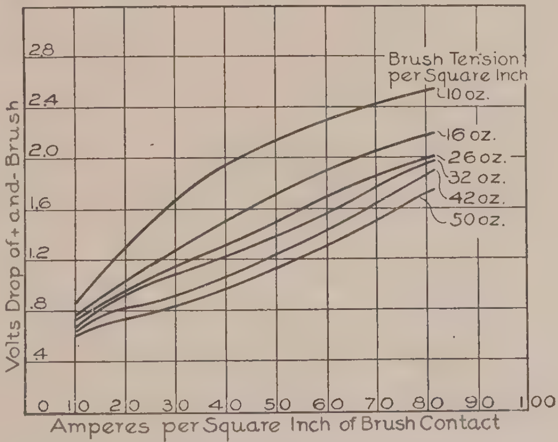


Fig. 140. Curves Showing Average Brush Drop with Various Brush Tensions and Current-Densities.

eters is $\frac{3}{4}$ that of the armature diameter, which serves as another guide.

Commutator Losses. The losses which the commutator surface must take care of may be divided into those arising from the resistance, or more properly the voltage drop, of the brush contact, and from the friction of the brushes against the rotating commutator. The former depends mainly upon the following factors:

(1) Material of the brushes.

(2) Pressure of the brushes upon the commutator.

(3) Peripheral speed of the commutator.

(4) Current-density in the brush.

(5) Condition of the commutator and brushes.

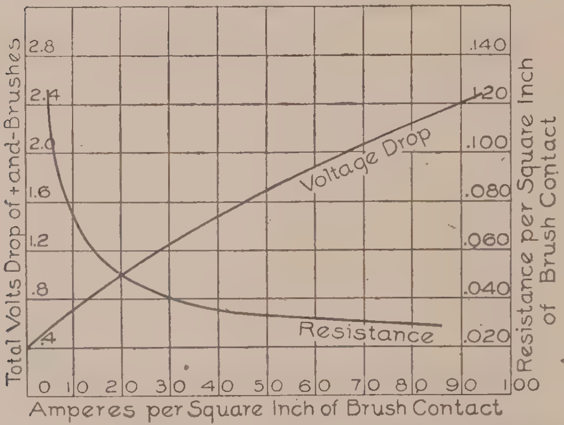


Fig. 141. Curves Showing Average Brush Drop and Contact Resistance at Various Current-Densities for Several Standard Grades of Carbon and Graphite Brushes.

The loss due to friction of the brushes upon the commutator varies with:

(1) Pressure of the brushes.

(2) Peripheral speed of the commutator.

(3) Coefficient of friction between commutator and brushes.

Fig. 141 shows the effect of various current-densities with various grades of brushes; and this may be taken as illustrating the influence of the material of the brush upon its contact resistance. Fig. 140 shows how the pressure of the brushes affects the voltage-drop; while Fig. 142 indicates the effect of peripheral speed of the commutator upon this drop, if we divide the watts loss by the amperes per square inch of brush contact; and Fig. 141 illustrates the relation between the current density in the brush and the voltage-drop across both positive and negative brushes. The influence of the condition of the commutator and brushes upon contact resistance cannot be stated exactly; but it is a fact that if either be in bad condition, the losses at the commutator may be increased many fold.

Multiplying the volts drop obtained from Fig. 141, by the current per brush set, we obtain the energy loss due to brush-contact resistance. For example, if we design the brushes so that the current-density in them is 35 amperes per square inch at rated load, we have a drop over the contact surfaces of both positive and negative brushes of 1.35 volts; and multiplying the total current output by 1.35 gives the watts lost.

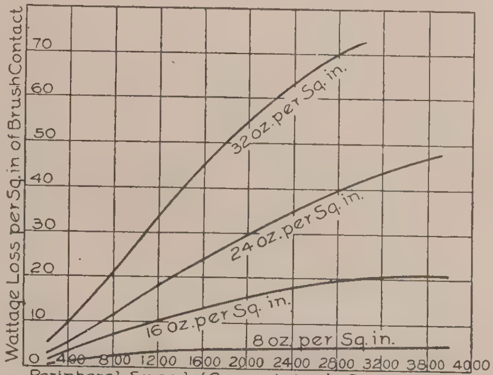


Fig. 142. Curves Showing Average Friction Loss per Square Inch of Brush Contact at Various Speeds and Brush Tensions.

Example. In a 100-kilowatt machine of one of the large manufacturing companies, the current collected by the brushes amounted to 415 amperes. If the current-density in the brushes had been 35 amperes per square inch, the loss due to contact resistance would have been:

$$1.35 \times 415 = 560 \text{ watts.}$$

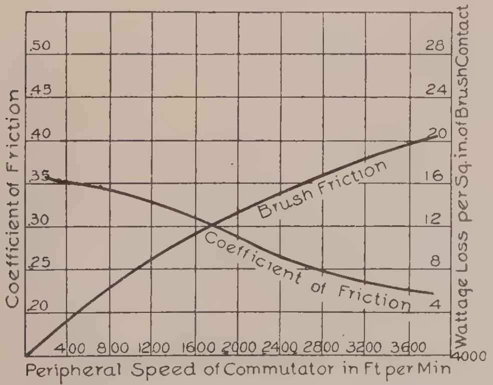


Fig. 143. Curves Showing Average Coefficient of Friction and Brush-Friction Loss for Different Grades of Brushes at Various Commutator Speeds, with Brush Tension of 1 lb. per Square Inch.

The variation of friction losses (which the surface of the commutator must radiate as heat) with peripheral speed of the commutator at various pressures, is shown graphically in Fig. 142; while the dependence of the coefficient of friction upon the commutator peripheral speed is indicated by Fig. 143 for carbon brushes in good condition.

To compute the watts lost through brush friction, multiply the total area of brush contact by the stress—*i.e.*, the pressure per unit area—to get the total pressure in pounds. Then multiply this value by the coefficient of friction and peripheral speed in feet per minute of the commutator, which gives the losses in foot-pounds per minute. Dividing by 33,000 to convert this value into horse-power, and multiplying by 746, we convert the result thus obtained into watts.

Example. Taking the same machine as just above mentioned, let us assume the brush pressure as 1.5 pounds per square inch, the total brush area as 23.7 sq. in., the peripheral speed of the commutator as 2,500 feet per minute, and the coefficient of friction as 0.27. We have the friction loss:

$$23.7 \times 1.5 \times 0.27 \times 2{,}500 \times 746 \div 33{,}000 = 543 \text{ watts (nearly)}.$$

Commutator Heating. The final temperature which the commutator surface will attain depends upon the total losses to be radiated by it and the radiating surface, together with the peripheral speed. According to tests made by Prof. E. Arnold, the final rise in temperature of the commutator in degrees Centigrade will be:

$$\theta = \frac{46.5 \times w_c}{A_c\,(1 + 0.005\,v)},$$

in which w_c represents the total commutator losses, electrical and mechanical, in watts; A_c represents the radiating surface of the commutator in square inches; and v represents the peripheral speed of the commutator in feet per minute.

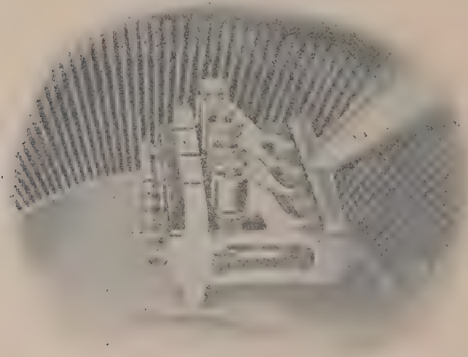
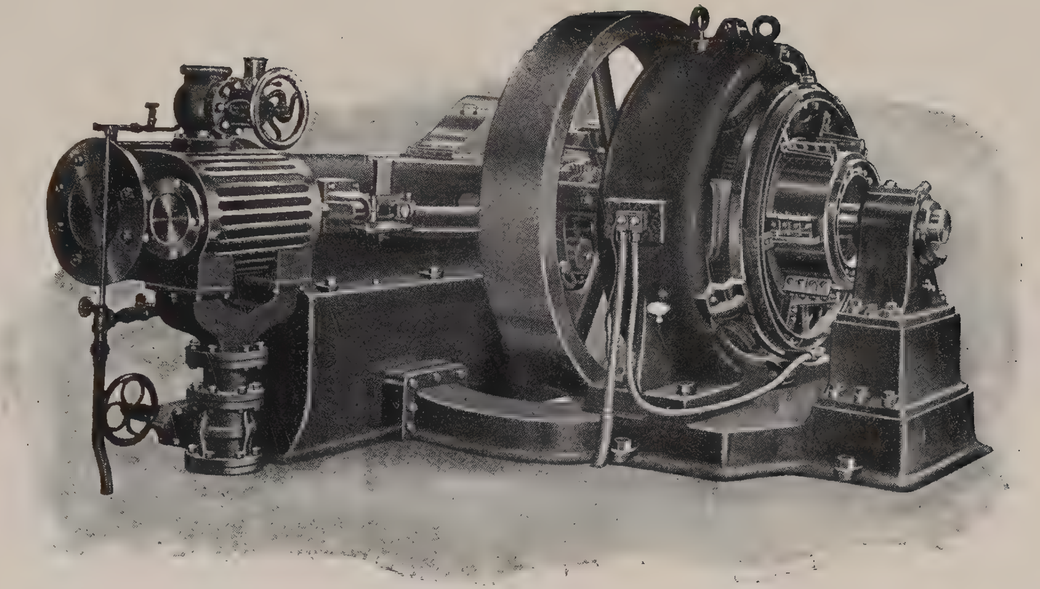


Fig. 144. Parallel Movement Brush-Holder. Crocker-Wheeler Company.

According to Messrs. Parshall and Hobart, the rise in temperature of the commutator will seldom exceed 20° C. with one watt per square inch of peripheral radiating surface at a peripheral speed of 2,500 ft. per minute, a figure which may be much improved upon with ventilated armatures.

Number and Size of Brushes. The total number of brush sets is usually fixed by the type of armature winding, as previously stated; but this criterion gives us no clew to the number of brushes per set. In all but the smallest machines, it is usual to place at least two brushes exactly similar, side by side (Fig. 144 shows four), instead of one broad brush, thus allowing one brush to be removed for trimming or



100 K.W. ENGINE-TYPE GENERATOR AND AUTOMATIC HIGH-SPEED ENGINE.

Triumph Electric Company.

renewal while the machine is running. The contact between the brushes and the commutator is made much better by this subdivision, for a slight inequality at one point of the latter may slightly raise one brush of a set at each revolution, without much harm, while, with one broad brush, the entire brush would be lifted, causing bad sparking. Subdivision of the brush also tends to equalize the wear upon the commutator, each brush being separately held against the commutator, and the gap between two adjacent brushes of the same set being bridged by the brushes of the other set or sets. The number of individual brushes in each group depends upon the current capacity and size of machine and the judgment of the designer, and varies from two to eight or more.

The proper thickness for carbon brushes cannot be stated definitely, but they are usually made to span $2\frac{1}{2}$ bars in armatures having simplex windings. For armatures with duplex and triplex windings, thicker brushes must necessarily be used. The usual thickness of metal brushes spans about $1\frac{1}{2}$ commutator bars.

Table VIII gives standard sizes of carbon brushes employed by most manufacturing companies; and in designing a generator or motor it is best to select one of these sizes that most closely approximates the requirements.

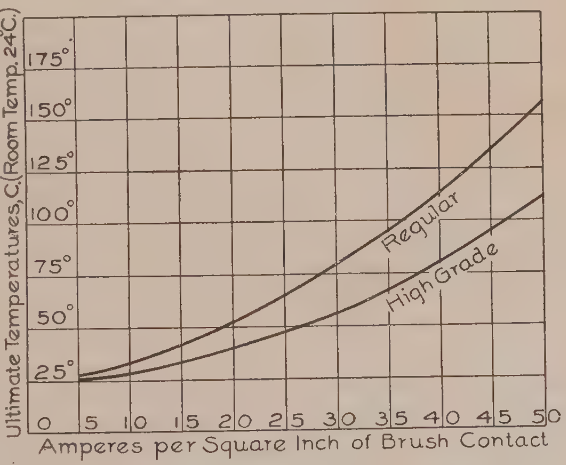


Fig. 145.—Average Temperature Curves of Standard Grades of Carbon or Graphite Brushes.

Heating of Carbon Brushes. Fig. 145 gives the variation of the temperature-rise of two well-known grades of carbon brushes with increase in the current-density employed. The room temperature at the time of the test was about 24° C., so that the values on the curves represent final or total temperatures. It is therefore necessary to deduct 24 from the values given by these curves, to realize the actual temperature-rise.

TABLE VIII

Standard Sizes of Carbon Brushes

Length Width Thickness	Length Width Thickness	Length Width Thickness	Length Width Thickness	Length Width Thickness	Length Width Thickness	Length Width Thickness
2½x2¼x ¼	3 x 1 x ¼	3½ x 1 x ¼	4 x 1 x ¼	5 x 1 x ¼	6x1½x ½	7x1½x ½
2½x2¼x ½	3 x 1 x ½	3½ x 1 x ½	4 x 1 x ½	5x1½x ¼	6x1½x ¾	7x2 x ½
2½x2¼x ¾	3 x 1 x ¾	3½ x 1 x ¾	4 x 1 x ¾	5x1½x ½	6x1½x1	7x2¼x ½
2½x2¼x1	3 x 1 x 1	3½ x 1 x 1	4 x 1 x 1	5x1½x ¾	6x1½x1¼	7x2½x ½
2½x2 x ½	3x1½x ¼	3½ x 2 x ¼	4x1½x ¼	5x1½x1	6x1½x1½	7x2½x ⅜
2½x2½x ¼	3x1½x ½	3½ x 2 x ½	4x1½x ½	5x1½x1½	6 x 2 x ½	7x2½x ⅝
2½x2½x ½	3x1½x ¾	3½ x 2 x ¾	4x1½x ¾	5 x 2 x 1	6x2½x ¾	7x2¼x ⅜
2½x2½x ¾	3x1½x1	3½ x 2 x 1	4x1½x1	5 x2 x 1¼	....	7x2¼x ⅝
2½x2½x1	3 x 2 x ¼	3½ x 3 x ¼	4 x 2 x ¼	5x2½x ¼	....	7x2¼x ¾
....	3 x 2 x ½	3½ x 3 x ½	4 x 2 x ½	5x2½x ½	....	7x2¼x ⅞
....	3 x 2 x ¾	3½ x 3 x ¾	4 x 2 x1⅜	5x2½x1	....	7x2¼x1
....	3 x 2 x 1	3½ x 3 x 1	....	....	....	7x2¼x1½
....	3 x 3 x ¼	3½x3½x ¼	....	....	....	....
....	3 x 3 x ½	3½x3½x ½	....	....	....	....
....	3 x 3 x ¾	3½x3½x ¾	....	....	....	....
....	3 x 3 x 1	3½x3½x 1	....	....	....	....
....	....	3½x3½x1½	....	....	....	....

CALCULATIONS OF MECHANICAL PARTS

General. The almost invariable practice is to have the magnet-yoke of a generator or motor serve as a frame for all the remaining parts, except in larger sizes, for which independent bearings are used. The strength of the material used in the field-ring is great, and as its bulk is large in comparison with the load sustained, it is rarely that mechanical calculations are made. In the case of the armature shaft, the arms or spokes for the spider, and the bearings, however, calculations are necessary, which will now be briefly considered.

Armature Shafts. The shafts of armatures are usually made of mild steel; and for their design, reference may be made either to standard works on machine design or to the formulæ below, based on the usual methods employed in that class of work, and modified to meet the requirements of electrical machinery. Shafts for the latter are generally made somewhat larger than for other machines, on account of the magnetic pull which comes upon the shaft when the armature is even slightly out of center of the poles, as already noted.

The diameter of that portion of the shaft within the armature core, Fig. 146, may be found from the following expression,

$$d_c = k_1 \sqrt[4]{\frac{W}{\text{r. p. m.}}},$$

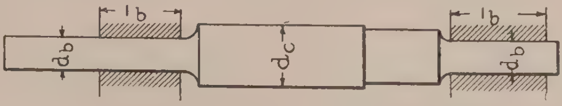


Fig. 146. Dimensions of Armature Shaft.

in which

d_c = Shaft diameter within the core, in inches;

k_1 = A constant depending upon the output of the machine as given in Table IX;

W = Output of the machine in watts.

The shaft diameter in the bearing or journal, may be computed from the following formula,

$$d_b = k_2 \sqrt{W} \sqrt[4]{\text{r. p. m.}}$$

in which

d_b = Diameter of the shaft in the bearing;

k_2 = A constant depending upon the speed of the machine (see Table X).

TABLE IX

Value of Constant in Formula for Diameter of Core Portion of Shaft

Capacity of Machine (in Kilowatts)	Value of k_1
Up to 1 kilowatt	1
1– 5 "	1.1
5– 10 "	1.2
10– 50 "	1.3
50– 100 "	1.4
100– 200 "	1.5
200– 500 "	1.6
500–1,000 "	1.7
1,000–2,000 "	1.8

TABLE X

Value of Constant in Formula for Diameter of Shaft in Bearing

Type of Armature	Value of k_2
High-speed drum armature	0.0025
High-speed ring armature	0.003
Low-speed drum armature	0.004
Low-speed ring armature	0.005

Armature Spider Spokes. Drum armatures in which the core consists of a ring of iron supported by means of a skeleton pulley or spider attached to the shaft, the winding being placed in slots in the circumference of the core, are called *ring-core* armatures, to distinguish them from *ring-wound* armatures such as shown in Fig. 30. Fig. 147 represents a ring-core, drum-wound armature in process of construction. In both cases the driving of the armature is effected by a number of spokes which respectively form part of the spider itself (Fig. 148) or of a separate frame keyed to the skeleton pulley (Fig. 149). The spokes are usually elliptical in cross-section, and are generally made of cast iron or steel. They should be designed adequately to support and drive the armature.

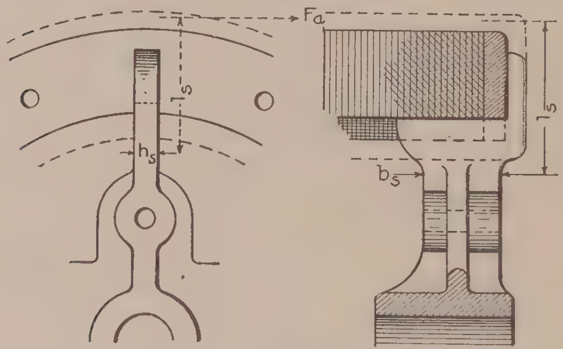


Fig. 147. Ring-Core Drum-Wound Armature in Process of Construction.

From a consideration of the bending and shearing moments acting upon such an arm or spoke (Fig. 149), it may be shown* that:

$$\frac{\pi\, b_s\, d_s^{\,2}}{32}\dagger \leqq \frac{100\, w\, l}{r\, n_s\, \text{r. p. m.}} \cdot \frac{1}{f_t}\,;$$

and,

$$b\, d \leqq \frac{100\, w\, l}{r\, n_s\, \text{r. p. m.}} \cdot \frac{1}{f_s}\,,$$

in order that the safe working stresses of the material utilized may not be exceeded. In these formulæ,

b = Breadth of an arm parallel to the shaft, in inches;

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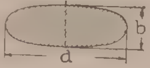
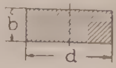
*See "The Dynamo," by Hawkins & Wallis, New York, 1903; p. 310.

† $\frac{\pi b_s d_s^2}{23}$ is known as the *modulus of resistance* of the section 

For the section 

it is $\frac{b_s d_s^2}{6}$; for the section

it is $\frac{\pi d^3}{32}$; and if any one of these sections be used, the corresponding section modulus should be substituted in the formula.

f_s = Safe working stress of the material for shearing, in lbs. per sq. in., which, for cast iron, is 5,000, and for cast steel 15,000;

f_t = Safe working stress of the material for tension or compression, in lbs. per sq. in., which is 1,250 for cast iron, and 5,000 for cast steel;

d = Thickness of the arm, in inches;

l = Distance from the tip of section whose breadth is b_s and whose thickness is d_s.

n_s = Number of spokes or arms;

r = Radius of an arm, in inches.

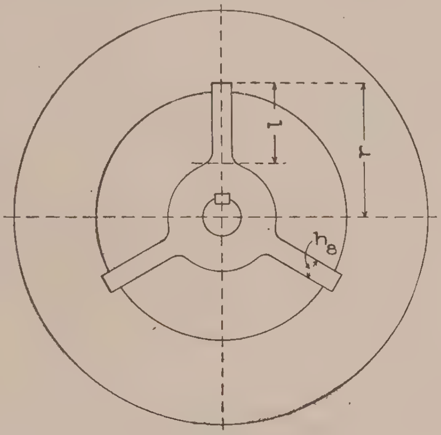


Fig. 148. Armature Driven by Spokes Forming Part of Spider.

Armature Binding Wires. In the case of toothed armatures, the conductors must be held in the slots. For this purpose it is customary to use wedges driven in under the tops of the teeth, or, in the case of straight teeth, to use a number of external bands known as *binding wires*. These must be strong enough to resist the centrifugal forces, and yet at the same time occupy very little radial depth, that they may not interfere with the clearance between the armature and the pole-faces. The almost invariable practice is to use a tinned wire of hard-drawn brass, phosphor-bronze, or steel, which, after winding, can be sweated together into a solid band. The ultimate tensile strength of phosphor-bronze is from 65,000 to 120,000 pounds per square inch, while that of steel wire varies from 120,000 to 250,000 pounds per square inch, the larger figures relating to the smaller sizes of wire.

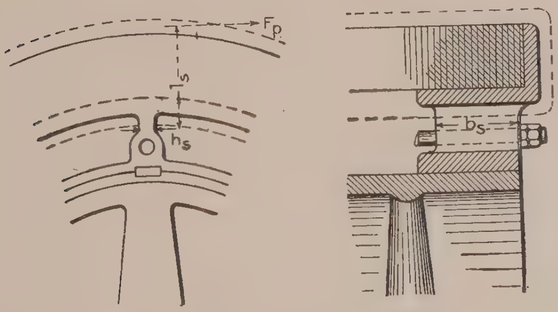


Fig. 149. Ring-Core Armature Driven by Pulley and End-Rings.

To estimate the proper size and number of binding wires required, we have that if d be the diameter (in inches) of the circular path described by a mass of weight w_1 pounds, the centrifugal force will be $= 0.0000143 \times d \times w_1 \times \overline{\text{r. p. m.}}^2$ pounds weight. So that if we assume a value of 100,000 pounds per square inch as the maximum allowable tensile stress in steel or phosphor-bronze wire, and allow a safety factor of say 10, the total section of binding wire required will be:

$$= \frac{0.0000143 \times 10 \times w_1 \times Z \times d \times \overline{\text{r. p. m.}}^2}{\pi \times 100{,}000}$$

$$= 4.55 \times 10^{-10} \times w_1 \times Z \times d \times \overline{\text{r. p. m.}}^2 \text{ square inches.}$$

From this total necessary section, and an appropriate wire table, the number of wires is then calculated, and they are then arranged in suitable belts.

Example. Let $w_1 = 0.39$ lb.; $Z = 1{,}536$; $d = 62$ in.; r. p. m. $= 150$. The total necessary section computed by the above formula is 0.379 square inch. Referring to the wire gauge tables, we find that 148 wires of No. 15 B. & S. gauge will fulfil the conditions. These may be arranged as follows: 5 belts of 16 wires each over the core body, and 4 belts of 17 wires each over the extended ends of the winding (*i.e.*, 2 belts of 17 wires each over each end).

Under each belt of binding wires, it is usual to lay a band of insulation. These bands generally consist of two layers, first a thin strip of vulcanized fibre or of hard red varnished paper slightly wider than the belt of wires, and then a strip of mica (in short pieces) of about equal width. Sometimes small straps of thin brass are laid under each belt of binding wires, having tags which can be turned over and soldered down to prevent the two ends of the binding wire from flying out.

Armature Bearings. Bearings for generators and motors should be very strong and rigid, with ample wearing surface, in order that the armature may not become materially displaced with respect to the poles as a result of magnetic attraction as well as weight, and also to prevent overheating of the journals. The following formula takes into account the increased generation of heat at higher peripheral velocities, and also provides sufficient wearing material:

$$l_b = k_3 \times d_b \sqrt{\text{r. p. m.}},$$

wherein

l_b = Length of the bearing, in inches;
d_b = Diameter of the shaft in the bearing (from page 129);
k_3 = A constant dependent upon the speed of the armature (given in Table XI).

TABLE XI

Value for Constant in Formula for Length of Armature Bearing

Capacity of Machine (in Kilowatts)	High-Speed Armatures	Low-Speed Armatures
Up to 5 kilowatts	0.1	0.15
" 10 "	0.1	0.175
" 50 "	0.125	0.200
" 100 "	0.150	0.225
" 500 "	0.175	0.250
" 1,000 "	0.200	0.275
" 2,000 "	0.225	0.300

Losses Due to Friction in the Bearings and to Windage. These are very difficult to predetermine with even reasonable accuracy. Designers usually estimate them from previous experience. For belt-driven machines ranging in speeds from 1,800 r. p. m. to 300 r. p. m. and of capacity from 30 to 500 kw., these losses should range from 3 per cent of the output in the smaller machines to 1 per cent in the larger sizes. For direct-connected generators, this figure ranges from 1 per cent to 0.4 per cent of the output, depending upon the size and speed, being lower for machines of this type on account of the lowered r. p. m. and the better alignment.

Calculation of Efficiency. On page 63, efficiency was defined as the ratio between output and input of the machine. It may also be defined as the ratio between the output and the output *plus* the losses. These latter come under the following heads, the computation of each having been considered in the foregoing pages:

(1) *Copper Losses.* These consist of the sum of the I^2R losses in the armature field-coils, and increase as the square of the current—being, however, independent of the speed.

(2) *Iron Losses.* These are made up of the eddy-current and hysteresis losses produced in the armature core-plates owing to the changes in flux-polarity and density to which they are periodically subjected. They vary slightly with load, on account of the strained distribution produced, and are always variable with the speed, eddy currents varying as the square of the speed, and hysteresis losses as the 1.6th power of the speed.

(3) *Excitation Losses.* These consist of the watts expended as heat and utilized to drive the magnetizing current around the magnetizing coils, and are included in machine I^2R losses.

(4) *Commutator Losses.* These losses may be subdivided into:

(*a*) I^2R loss due to brush-contact resistance;

(*b*) Brush friction loss.

(*c*) Losses through sparking and through eddy currents in the commutator bars.

Of those, *a* and *b* are the only ones usually considered, the other being practically negligible except in generators furnishing very large currents at very low voltages.

(5) *Bearing Friction and Windage Losses.* The former are the losses due to the friction of the shaft in the bearings, and depends only upon the load and speed. The latter are occasioned by the armature churning the air, and are independent of the load, but vary with the speed.

(6) *Secondary Copper and Iron Losses.* These have already been considered as eddy-current loss in the armature conductors, eddy-current loss in the pole-faces, etc.

The method of calculating each of these losses has been considered in detail above, so that we have;

$$\eta = \frac{w_0}{w_0 + w_1 + w_2 + w_3 + w_4 + w_5 + w_6},$$

wherein w_0 is the output of the machine in watts, and w_1, w_2, w_3, etc., represent the losses in watts just enumerated. Representative curves of these losses are shown on pages 15 and 123; while Table XII gives the average efficiencies and apportionment of losses of direct-driven machines of various sizes.

TABLE XII

Average Efficiencies and Apportionment of Losses of Direct-Driven Machines of Various Sizes

Output of Machine (in kw.)	Commercial Efficiency (per cent)	Percentage Losses In				
		Armature Copper	Armature Iron	Field Copper	Commutator, Friction and Drop	Friction and Windage
1	80	4.3	3.7	8	0.6	3.4
2	82	4.0	3.4	7	0.57	3.03
5	84	3.7	3.1	6	0.54	2.68
10	86	3.4	2.8	5	0.50	2.30
20	88	3.1	2.5	4	0.46	1.94
30	89.5	2.8	2.2	3.5	0.42	1.58
50	91.0	2.5	1.9	3.0	0.39	1.21
100	92.0	2.2	1.6	2.75	0.37	1.08
200	93.0	1.9	1.4	2.50	0.35	0.85
300	93.5	1.7	1.35	2.35	0.33	0.77
500	94.0	1.6	1.25	2.15	0.31	0.69
1,000	95.0	1.45	1.10	1.65	0.29	0.51
2,000	96.0	1.30	1.00	1.10	0.27	0.33

In using this table, it must be borne in mind that the values may vary considerably, even in machines of the same output but of different speeds and voltages, and under different conditions of working. The figures given should be used merely as a guide in apportioning or checking the losses.

Calculation of Magnetization Curve and Voltage Drop.—*Predetermination of Magnetization Curve.* The magnetization curve of a dynamo-electric machine is the curve connecting the ampere-turns upon the magnetic circuit, and the useful flux produced by them in the armature teeth. Since the number of turns upon the field coils is usually constant, and since the no-load terminal voltage of a generator is directly proportional to the useful flux entering the teeth of the armature, it is more convenient to represent the magnetization curve by the relation between the field-exciting current in amperes, and the no-load terminal voltage. This curve is generally predetermined by calculation, and then actually tested in the finished machine for each new type, thus checking the correctness of the designer's assumptions. The experimental determination is explained later. These curves are valuable, not only to show the character of one particular machine, but are useful for comparing different ones. For this purpose a standard ratio of the scales on which the curves are based should be followed.

To illustrate the method of constructing the magnetization curve of a continuous-current generator, let us consider the case of a generator the dimensions and particulars of which are as follows:

GENERAL:

Rated load output in kilowatts	150
Terminal voltage at rated load	250
External current, in amperes, at rated load	600
Armature speed, in r. p. m.	450
Number of poles	6

ARMATURE DIMENSIONS:

External diameter of core, in inches	33
Internal “ “ “ “ “	18
Number of slots	124
Depth of each slot, in inches	1.625
Width “ “ “ “ “	0.400
Pitch of slot at armature face, in inches	0.840
Radial depth of iron in core under teeth, in inches	5.875
Total length of core, in inches	11.
Iron length of core, in inches	9.
Number of conductors	496
Style of winding	parallel
Bare dimensions of each conductor, in inches	0.7 by 0.11
Insulated dimensions of each conductor, in inches	0.73 by 0.14
Mean length of one armature turn, in inches	66

FIELD-MAGNET DATA:	
Number of poles	6
Diameter of bore, in inches	33.625
Turns per pair of poles	3,602
Shunt exciting current, in amperes	4.10
Angle covered by each pole-face, in degrees	43
COMMUTATOR DIMENSIONS:	
Diameter, in inches	21
Number of segments	248
Active length, in inches	7.5

The magnet-cores are of steel, circular in cross-section and bolted to the yoke, the pole-shoes being in one piece with the magnet-cores. The field frame is cast in two pieces and bolted together. All the field-exciting coils are connected in series. The armature slots are parallel-sided, of the dimensions stated above. There are two ventilating apertures in the core, each $\frac{3}{8}$ inch wide. The armature winding has six circuits in parallel, with six sets of brushes set 60° apart.

In order to construct the magnetization curve, we have:

$$E = \frac{\phi_a \times Z \times \text{r. p. m.}}{60 \times 10^8} \quad \text{(see page 62.)}$$

$$= \frac{496 \times 450}{60 \times 10^8} \times \phi_a$$

$$= 0.00000372 \ \phi_a$$

As the leakage coefficient of this machine is $\nu = 1.11$ (from Table II, page 77), we may construct the following table, since $\phi_m = \nu \, \phi_a$ (from page 76):

E	ϕ_a	ϕ_m
200	5,370,000	5,960,000
230	6,170,000	6,850,000
260	6,980,000	7,750,000
280	7,510,000	8,350,000
300	8,050,000	8,940,000

From the drawings we find:

Mean length of magnetic path in magnet-yoke, in inches	26
" " " " " " two magnet-cores, in inches	28
" " " " " " armature core, in inches	15
" " " " " " two teeth, in inches	3.25
" " " " " " two air-gaps, in inches	0.625
Magnetic area of yoke, in square inches	44
" " " magnet-cores, in square inches	78.5
" " " armature body, in square inches	53

The polar angle being 43°, we have, for the number of teeth under one pole:

$$\frac{124 \times 43^\circ}{360^\circ} = 14.7.$$

Allowing for spreading of flux in the air-gap owing to high flux-density in the teeth, we may take 16 teeth as receiving flux from each pole.

As the pitch of slots at the bottom of the slots is $\frac{93.45}{124} = 0.754$ in., and as the slots are 0.4 inch wide, we have as the width of a tooth at its root, $0.754 - 0.400 = 0.354$ inch. The area of the teeth receiving flux from each pole will therefore be:

$$16 \times 0.354 \times 9 = 51 \text{ square inches,}$$

since the length of iron in the armature parallel to the shaft is 9 inches.

The air-gap area, taken as the pole-face area, is 140 sq. in.

This completes the data necessary for computation of the magnetization curve, and it is sufficient here to calculate a few points on this curve, as the method is the same for all.

Considering the machine to generate an e. m. f. of 200, 230, 260, 280, and 300 volts respectively, we obtain from the previous table, by the method explained on page 82, the accompanying tabulation (page 138).

As seen from this tabulation, we have:

$E = 200$, Ampere-turns per pair poles = 8,715
$E = 230$, " " " " " = 10,846
$E = 260$, " " " " " = 13,833
$E = 280$, " " " " " = 16,498
$E = 300$, " " " " " = 19,095

By plotting the curve connecting these five points, we obtain the working portion of the magnetization curve shown in Fig. 150. The complete magnetization curve may similarly be computed for the full range of the field-exciting current, taking account of the residual magnetism of the magnetic circuit; but in the design of generators, the working portion is sufficient.

It is usual to operate shunt-wound generators upon that portion of the magnetization curve just above the so-called bend, while compound-wound machines are usually designed to operate near the bend of the magnetization curve.

Computation of Voltage Drop from Magnetization Curve. At any generator load, there are four causes tending to lower the voltage at the terminals of the machine—namely, ohmic resistance of the armature and series coils (if any), drop due to brush contact, demagnetizing action of the armature, and distortion of the armature flux.

APPLICATIONS OF MAGNETIZATION CURVE CALCULATIONS

PORTION OF MAGNETIC CIRCUIT	MATERIAL	MEAN LENGTH OF MAGNETIC PATH (Inches)	MAGNETIC AREA (Square Inches)	$E = 200$ $\phi_a = 5{,}370{,}000$ $\phi_m = 5{,}960{,}000$			$E = 230$ $\phi_a = 6{,}170{,}000$ $\phi_m = 6{,}850{,}000$			$E = 260$ $\phi_a = 6{,}980{,}000$ $\phi_m = 7{,}750{,}000$			$E = 280$ $\phi_a = 7{,}510{,}000$ $\phi_m = 8{,}350{,}000$			$E = 300$ $\phi_a = 8{,}050{,}000$ $\phi_m = 8{,}940{,}000$		
				Flux-Density	Ampere-Turns per Inch Length	Ampere-Turns	Flux-Density	Ampere-Turns per Inch Length	Ampere-Turns	Flux-Density	Ampere-Turns per Inch Length	Ampere-Turns	Flux-Density	Ampere-Turns per Inch Length	Ampere-Turns	Flux-Density	Ampere-Turns per Inch Length	Ampere-Turns
Magnet-Yoke...	Cast Steel	26	2x44	67,800	12.5	325	77,900	18	468	88,000	25.5	663	94,900	37	962	101,500	56	1,455
2 Magnet-Cores.	do	[illegible]	78.5	76,000	16.5	462	87,200	25.0	700	98,600	47	1,315	106,200	76	2,125	113,900	107	2,995
2 Air-Gaps......	Air	0.625	140	38,400	120,100	7,503	44,100	13,800	8,630	49,900	15,600	9,750	53,700	16,800	10,500	57,500	18,000	11,250
2 Teeth..........	Sheet Steel	3.25	51	*105,000	119	387	*117,500	305	991	*130,500	625	2,030	*137,500	830	2,798	*144,000	998	3,222
Armature Core.	do	15	2x53	50,600	2.5	38	58,300	3.8	57	65,900	5	75	71,000	7.5	113	76,000	11.5	173
Ampere-turns per pair of poles.......				......	......	8,715	......	......	10,846	......	......	13,833	......	.....	16,498	......	......	19,095

* Corrected as per curves on page 81.

The voltage-drop due to resistance of the armature winding, series field-coils, and brush contacts, is:

$$e = I_a r_a + I_a r_{se} + I_a r_b,$$

omitting the second term if the series winding is absent. Then, in the assumed case (Fig. 150), the no-load e. m. f. being 250, represented by *P* on the magnetization curve, the rated-load current being 600 amperes, and the resistance of the main circuit (including brushes, armature winding, and series field-winding) being 0.00893 ohm, we have:

$$e = 0.00893 \times 600 = 5.4 \text{ volts},$$

which, added to 250, shows that the generated e. m. f. at rated load would have to be 255.4 volts, without considering armature reaction. This is represented by the point *O* on the saturation curve; hence 13,500 ampere-turns are required to generate this e. m. f. In other words, at rated load and speed, assuming the terminal voltage to remain the same as at no load, we require 13,500 ampere-turns upon the field, assuming armature reaction absent.

As it is often convenient to check the dimensions of an armature conductor in a preliminary design by means of this voltage-drop, Table XIII is herewith given:

TABLE XIII

Voltage-Drop as Related to Output in Shunt and Compound Machines

OUTPUT OF MACHINE (in kilowatts)	VALUE OF e AS A PERCENTAGE OF RATED-LOAD TERMINAL e. m. f.	
	SHUNT MACHINES	COMPOUND MACHINES
5	7	10
10	6	8
25	5	7
50	4	6
100	3.5	5
200	3	4
500	2.5	3
1,000	2	2.5
2,000	1.5	2

With regard to the demagnetizing ampere-turns of the armature, we know that in general these are the ampere-turns lying within twice the angle of brush lead. Assuming the brushes to be set just under the pole-tips at rated load, the demagnetizing ampere-turns will be the number of armature conductors lying between adjacent pole-corners, multiplied by the current in them.

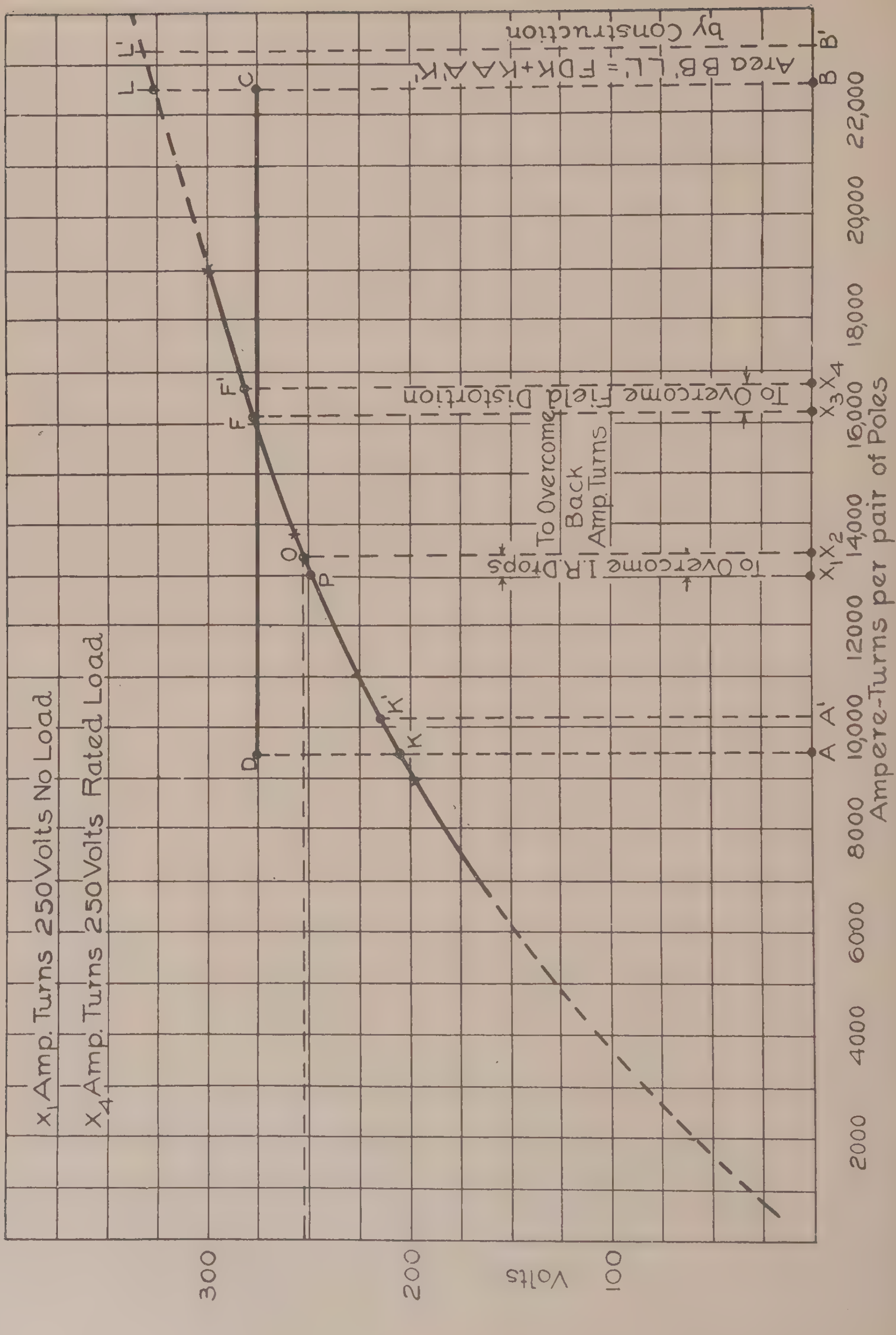


Fig. 150. Magnetization Curve of a Continuous-Current Generator.

These ampere-turns are multiplied by the leakage coefficient (because they have to be neutralized by the field-winding); the result is added to X_2, and set off on the diagram as X_3 (Fig. 150). By projecting this up to the curve, the point F is obtained, which corresponds to the necessary e. m. f.

Example. In the case previously considered, the number of slots lying between pole-tips is,

$$\frac{60° - 43°}{360°} \times 124 = 5.8;$$

and in each slot there are four conductors, each carrying 100 amperes at rated load. Hence the demagnetizing ampere-turns of the armature at rated load per pole (assuming that the brushes are moved right under the pole-tips, and that the leakage coefficient is 1.17), are:

$$5.8 \times 4 \times 100 \times 1.17 = 2{,}715.$$

Adding these ampere-turns to X_2, we get $X_3 = 16{,}200$ as the total ampere-turns required at rated load, assuming that there is no drop in voltage caused by diminished permeability in the teeth at the forward pole-horn due to distortion of the flux.

With a smooth-core armature, the flux distortion in the air-gap does not produce a diminution in the terminal voltage of the machine; but with toothed armatures, allowance must be made. In Fig. 151, let AB represent the width of the pole-face to scale, and EF the flux-density in the air-gap B_g. Then the area $ABCD$ is proportional to the useful flux ϕ_a, and at no-load we may regard this flux as being uniformly distributed along the air-gap as indicated by said rectangle. Assuming the permeability of the teeth to be constant, and laying off AH as the flux-density at the hindward pole-horn, and BG as the flux-density at the forward pole-horn (the flux being heaped up in the latter at rated load, and withdrawn from the former), the line HFG would represent the flux-density variation from point to point in the air-gap, and the area $AHGB$ would be equal to the area $ABCD$, since the permeability of the air-gap is constant. But the increased flux-density at the forward pole-horn causes the permeability of the teeth at this point to have a much lower value than it has with the flux-density B_g,

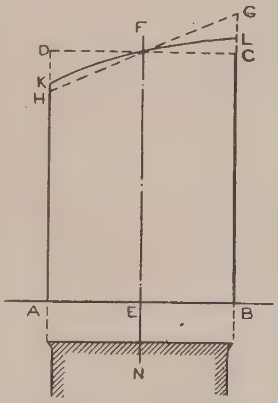


Fig. 151. Curve Showing Relation between Pressure Drop and Flux-Distortion in Air-Gap.

while, on the other hand, the permeability of the teeth under the hindward pole-horn has increased on account of the diminished flux-density in them. As a result, the line *HFG* takes the bent form shown by the curve *KFL*, and the *shape of this curve is the same as that of the magnetization curve over this range.* As can readily be seen from the figure, the area *AKLB* is considerably less than the area *AHGB;* that is, there is a diminution of the useful flux ϕ_a, and consequently a corresponding voltage drop, which will as a rule be greater, the higher the flux-density in the teeth.

One way to estimate the number of ampere-turns needed to compensate the effect produced by the distortion of the useful flux, is as follows:

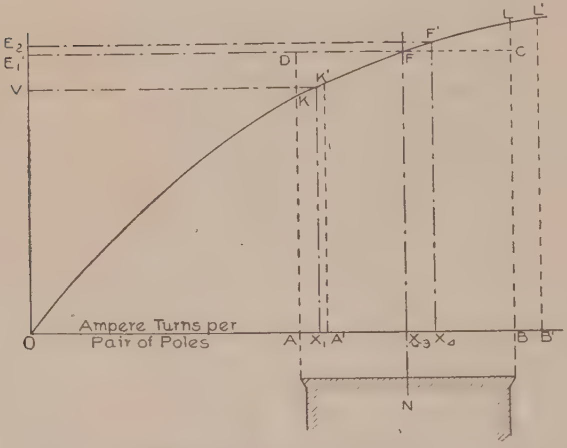
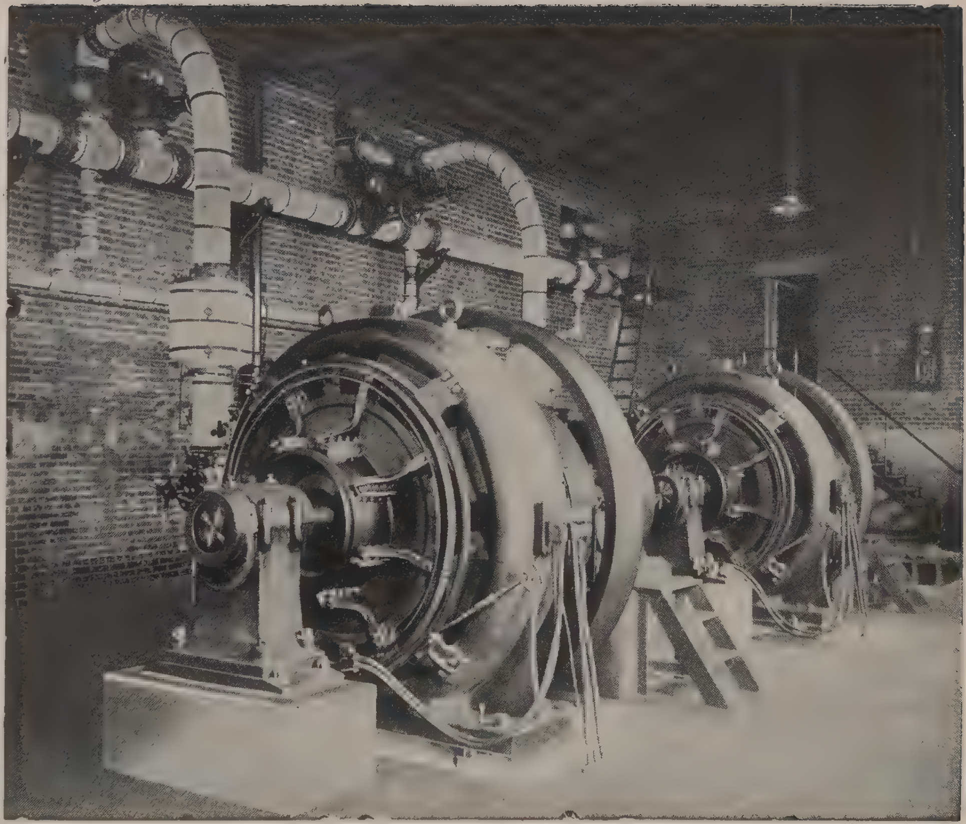


Fig. 152. Calculating Ampere-Turns Required to Compensate for Distortion of Useful Field.

In Fig. 152, let *OL* be the magnetization curve of the machine, the ampere-turns required for no-load, and those for rated-load induced e.m.f. at no load (and, therefore, without the extra allowance for distortion) being set off upon its scale of abscissæ *OX*, as X_1 and X_3, respectively, these having been estimated as shown in Fig. 150. Now, upon *OX*, mark off *OA* and *OB* as shown in the figure. The point *A* then represents the hindward pole-horn, and the point B the forward pole-horn. Had the distortion been absent, the ampere-turns required to produce E_1 volts would have produced a flux across the gap proportional to the area of the piece *ABCD*. But, as the distortion is present, the flux is proportional to the smaller area *ABLK*. Hence, we shift the point *F* higher up the curve to a point such as *F′*, so that the area *A′B′L′K′* equals the area *ABCD*. This gives a new point X_4 along *OX*, representing the rated-load ampere-turns required. Consequently, for a compound-wound machine, the series ampere-turns



DIRECT-CONNECTED GENERATORS
Operating the Largest Woodworking Plant in the United States.
Triumph Electric Company.

must be $X_4 - X_1$, and the shunt ampere-turns X_1, in order that the terminal volts may be OV at rated load. If the machine is shunt-wound, the resistance of the shunt rheostat must be capable of reducing X_4 ampere-turns to X_1 ampere-turns. And if there are to be neither series turns nor shunt regulator, the drop from rated load to no load would be $OE_2 - OV$ at constant speed.

Applying this reasoning to the machine under consideration, we have, for the ampere-turns under one pair of poles:

$$\frac{47^\circ}{360^\circ} \times 124 \times 4 \times 100 = 6{,}500.$$

The first factor being the slots under each pole, the second the number of inductors per slot, and the third the current per inductor, we set off, therefore, 6,500 ampere-turns on each side of the point X_3 (Fig. 150), and obtain thus the points A and B, which represent the hindward and forward pole-horns respectively. If the distortion of the main flux were absent, the area of the rectangle $ABCD$ would be proportional to it. But as this is not so, it is proportional to the smaller area $ABLK$. In order to make this latter area equal to that of the rectangle, we must shift the point F higher up on the curve to the position F', so that area $A'B'L'K'$ = area $ABCD$. In this manner we obtain the point X_4 as the necessary ampere-turns at rated load. Its value is: $X_4 = 16{,}800$.

The method just discussed for predetermining the series (compound) winding needed to give constant terminal e. m. f. at all loads between zero and rated load, may easily be extended to the case of over-compounding, by adding to the calculated voltage-drop in the machine the required increase in terminal voltage.

This method, although one of the most satisfactory, does not permit of great accuracy; but fortunately this is not important. By designing the shunt regulator liberally, and by placing a shunt across the series field-coils, the desired result may be reached by trial. This is in fact the practice of almost all dynamo builders.

The possible discrepancies between calculations thus made and results of actual test, are shown by the following values of the ampere-turns required at no-load and at rated load, as determined by the manufacturers of the machine we have been discussing:

OUTPUT	CALCULATED VALUES	ACTUAL VALUES
No-load	13,400	13,000
Rated-load	16,800	15,300

The difference was caused, no doubt, by the fact that better quality of iron was used in the machine than that for which the ampere-turns were computed.

EXPERIMENTAL DETERMINATION OF CHARACTERISTIC CURVES OF CONTINUOUS-CURRENT GENERATORS

Dr. John Hopkinson, in 1879, first suggested that the behavior of a generator could best be studied from a curve representing the relation between the e. m. f. and current of the machine at different loads. In 1881, M. Marcel Deprez elaborated Hopkinson's method and gave the name of *characteristics* to these curves.

At present the characteristics most commonly developed are:

(1) Magnetization curve.

(2) External characteristic.

(3) Curve of flux distribution (explained on page 39).

Experimental Magnetization Curve. The method of predetermining the magnetization curve of any continuous-current generator was explained on page 135.

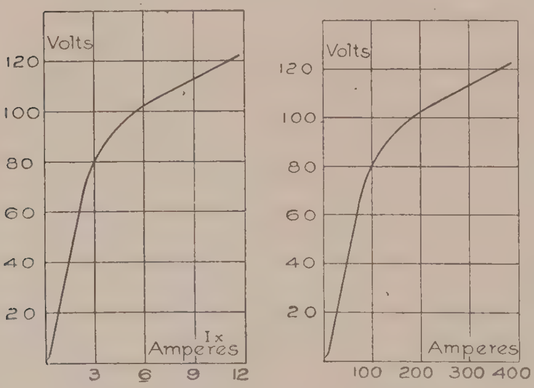


Fig. 153.

Fig. 154.

Curves Showing Effects of Residual Magnetism on the Magnetization Curve of a Dynamo.

The magnetization curve of a dynamo, however, can be determined experimentally by driving it at rated speed, and observing the voltage at the terminals for different values of the current sent through the field-winding from some outside source. Figs. 153 and 154 are typical magnetization curves of a 30-kw. generator; Fig. 153 shows the magnetization curve of the machine when its field is wound with many turns of fine wire (*i.e.*, a shunt dynamo); and Fig. 154 shows the magnetization curve of the same machine when its field is wound with a few turns of coarse wire (*i.e.*, a series dynamo).

Dependence of the Magnetization Curve upon Speed. When the magnetization curve of a dynamo has been determined for a given speed (n), the curve for any other speed (n') can be found by multiplying the ordinates of the given curve by $n' \div n$. This is evident when we consider that the flux ϕ_a has a definite value for each value of field current, so that the generated e. m. f. is proportional to the speed.

Effect of Residual Magnetism. When the field-exciting current of a generator is zero, the flux in the armature is in general *not* zero, on account of residual magnetism. This effect is indicated in Figs. 153 to 155, for it is seen here that when the field-exciting current is zero, the generated e. m. f. has a definite value.

Effect of Hysteresis. On account of hysteresis in the iron portions of the magnetic circuit, the flux in the armature, and hence the no-load terminal voltage, corresponding to a given value of the field-exciting current, is smaller when the latter is increasing than when it is decreasing. Therefore the magnetization curve of a dynamo for increasing field-current, is slightly lower than that for decreasing field-current, as shown in Fig. 155. This effect of hysteresis upon the magnetization curve of a generator is usually ignored in discussing the relation to other characteristic curves. In fact, the effect of hysteresis is greatly diminished in practical operation, inasmuch as the mechanical vibrations of the machine and the slight

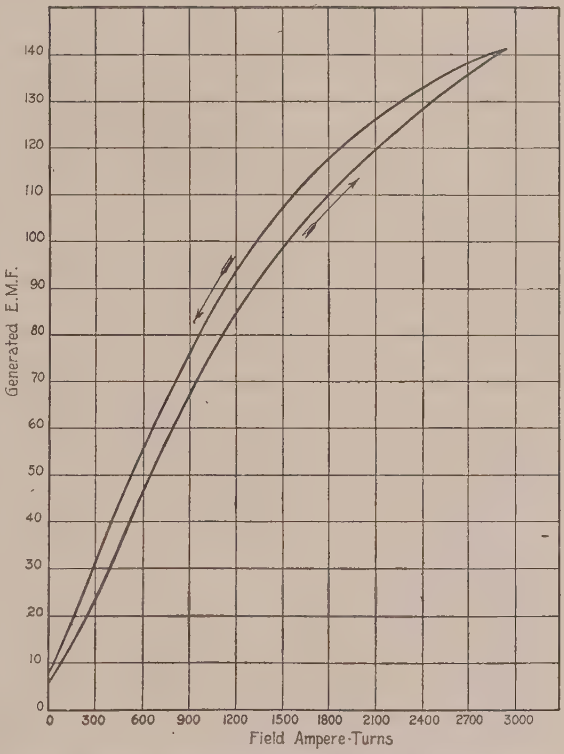


Fig. 155. Magnetization Curves of a Dynamo with Increasing and Decreasing Field-Current.

pulsations of armature and field currents, cause the flux to settle to a normal value.

External and Other Characteristic Curves. The external characteristic curve of any dynamo-electric machine is a curve representing the relation between the terminal voltage of the machine and the external load in amperes. Besides the external characteristic curve, the *total characteristic curve*, and the *ampere-ohm characteristic curve* are sometimes considered. The former represents graphically the relation between the generated e. m. f. of the machine and the armature current, while the latter shows the relation between output of the machine in amperes and resistance of the external circuit. Inasmuch as the characteristic curves of the series, shunt, and compound generators differ markedly from one another, those pertaining to each type will be considered separately.

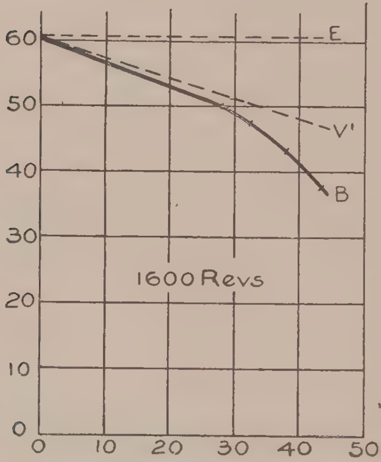


Fig. 156. Characteristic Curve of Separately-Excited Dynamo.

Characteristic Curves of Magneto and Separately-Excited Machines. In the magneto machine, the permanent magnetism of the steel may be considered approximately constant, and the same condition would obtain in a separately-excited machine if the field-current were kept constant. Owing, however, to the reactions of the armature when the current flows therein, the useful flux and terminal voltage are decreased. In Fig. 156 are given the results of tests upon a separately-excited dynamo. The line *E* represents the generated e. m. f. of the machine when operated on open circuit at rated speed and field-current. The line *V'* shows the terminal voltage which would be obtained if armature reactions were absent, and only armature and brush drop were in evidence. The curved line *B* represents the actually observed values of the terminal voltage when different currents were drawn from the machine. The pronounced droop at the lower end of the latter curve is probably due to the greater demagnetizing effect when there is a considerable lead at the brushes.

The characteristic shows such a downward curvature more definitely when the field-magnets are weakly excited.

Characteristic Curves of Series-Wound Machines. The characteristic curve of a series generator may be determined experimentally by driving the machine at constant speed, and observing corresponding values of current output and terminal voltage for different resistances in the external circuit.

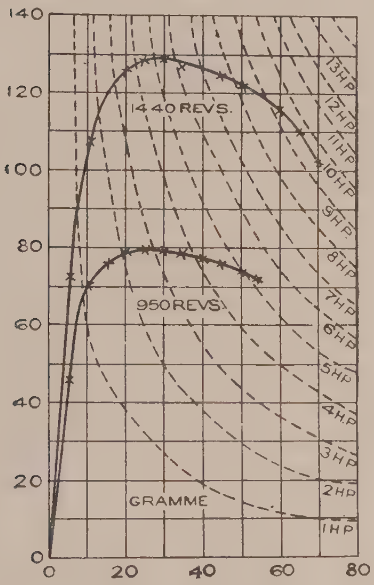


Fig. 157. Characteristic Curves of a Series-Wound Generator at Different Speeds.

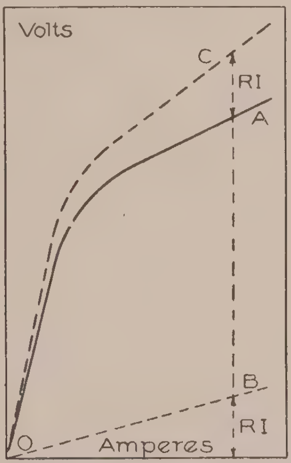


Fig. 158. Effect of Residual Magnetism on Characteristic Curve of a Series-Wound Generator.

External Characteristic Curve. Fig. 157 represents the external characteristic curves of an "A" Gramme machine, series-wound, at two different armature speeds. As is seen from the shape of the curves, the e. m. f. increases at first with the current, due to the increase in magnetization of the field-magnets. As the parts of the magnetic circuit, with increase of load, approach saturation, the reactions of the armature and I R drops become of relatively greater importance; the result is that the curve flattens out and finally bends downward.

Total Characteristic Curve. The total characteristic curve shown in Fig. 158 was plotted from the external characteristic in the following manner: Knowing that,

$$E^* = V + (r_a + r_{se} + r_b)\, I_a = V + R\, I_a\,,$$

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* Page 66.

and since the armature and external currents of this type of generator are equal, we plot the values of I_aR for various values of I_a, obtaining the straight line OB in the figure. Adding to each ordinate of the external characteristic curve, the corresponding value of the I_aR drop thus found, we obtain the total or internal characteristic as shown.

The effect of residual magnetism upon the external and total characteristic curves of a series-wound generator causes the curve to intersect the axis of volts above the origin, as indicated in Fig. 158; that is, at zero external current, and hence zero field-exciting current, an e. m. f. is generated in the armature of small value, as already explained. Thus a series generator is self-starting.

Relation between Magnetization Curve and Total Characteristic Curve of a Series-Wound Generator. If it were not for the demagnetizing action of the armature current on the field, the total characteristic curve of a series-wound generator would be almost identical with the magnetization curve. The effect of the armature current is, however, either to reduce inducing flux and therefore the generated voltage which corresponds to a given field-exciting current, or to necessitate an increased field-exciting current to give the requisite terminal voltage.

Dependence of the Characteristic Curve on Speed. Since the flux has a definite value for a given value of current output of a series-wound generator, and therefore independent of the speed, the generated voltage is proportional to the speed for a given value of the output current. The external characteristic curve corresponding to the speed n' may in consequence be derived from the external characteristic curve corresponding to the speed n, as follows: Add IR to each ordinate of the given characteristic, thus finding the total characteristic for the same speed n.* Then multiply the ordinates of this characteristic curve by $n' : n$, thus finding the total characteristic curve for the speed n'. Subtract IR from each ordinate of this curve, thus obtaining the external characteristic curve for the speed n'.

Drooping of the External Characteristic Curve. It would seem as though the useful flux entering the armature teeth of a series-wound generator should increase more and more with the current output of the machine. As a matter of fact, the effect of magnetic leakage around the armature caused by the reactions of the armature current, is to cause this useful flux actually to decrease in value when the current output is excessive, especially if the iron in the field-circuit becomes saturated before that in the armature circuit. This decrease in the useful flux entering the armature means an actual decrease in the generated e. m. f.; and of course the terminal voltage falls off, though more than that generated on account of I_aR drop, as shown in Figs. 157, 158, and 159.

---

* n = Initial speed; n' = Final speed.

Fig. 159 shows the external characteristic curve (full line), and total characteristic curve (dotted line), of a Wood arc-light, series-wound generator, with its governing device for maintaining a current of nine amperes disconnected (as indicated by the broken line pI).

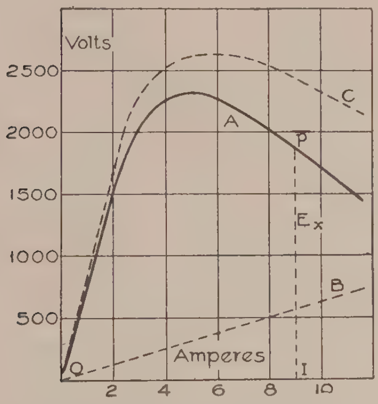


Fig. 159. External (Full-Line) and Total (Dotted) Characteristic Curves of a Wood Arc-Lighting Series Generator with Governing Device Disconnected.

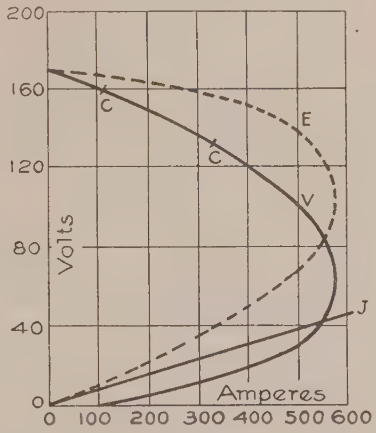


Fig. 160. Characteristics of a Shunt Dynamo.

Characteristic Curves of Shunt=Wound Generators. The external characteristic curve of the shunt-wound generator is determined experimentally by running the machine at rated speed and noting the terminal voltage for various values of the external current.

External and Total Characteristic Curves. The full line in Fig. 160 represents the external characteristic curve of a typical shunt-wound generator, the portion *cc* being that part upon which machines of this type are usually operated.

The total or internal characteristic curve is shown by the broken line in the same figure, and is calculated from the external characteristic curve as follows: Consider a point upon the external characteristic curve. The corresponding point upon the total characteristic curve is found by increasing the abscissa by the value of the shunt current so as to obtain the armature current, and by adding to the ordinate the voltage-drop in the armature and brush contacts to get the generated e. m. f.

These are seen to differ radically from the corresponding curves of the series-wound machine. The figure shows that the curves begin at a point where the terminal and generated volts are maximum, and descend slightly at first and then rapidly, finally returning in the direction of the origin, but cutting the axis of abscissæ before reaching it. The straight portion of the curve, after the bend, represents the unstable state when the shunt current is less than its true critical value. The slope of the line which constitutes the latter portion of this characteristic, represents for this particular speed, that external resistance below which the magnets lose their magnetism at once.

The effect of residual magnetism upon the external characteristic curve of a shunt-wound machine is to cause it to intersect the ampere-axis to the right of the origin, as indicated in Fig. 160.

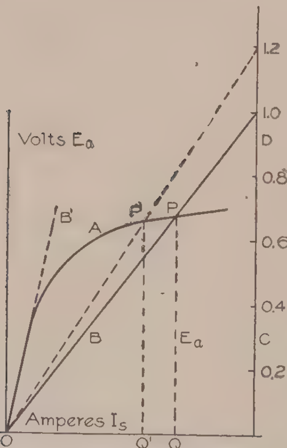


Fig. 161. Relation between Voltage and Speed in Shunt Generator.

Voltage-Speed Characteristic Curve of Shunt Generator at No-Load. The relation between the speed of a shunt generator and its voltage is much more complicated than in the case of the separately excited or series-wound machines, since a higher speed increases the generated e. m. f. It thus causes a greater exciting current to flow in the field-windings, resulting in a still higher value of machine voltage until practical saturation is reached. We may construct the curve showing this relation from the magnetization curve of the machine, as follows: Let OA, Fig. 161, be the magnetization curve of a shunt-wound machine at a speed n. Draw the straight line OB, of which the abscissæ represent values of the shunt field-exciting current I_{sh}, and the ordinates represent values of the voltage $r_{sh}I_{sh}$ required to produce the corresponding values of I_{sh}. The co-ordinates of the point of intersection of OA

and OB will then represent the values of E, which is practically equal to V at no load, and to I_{sh} when the machine is driven at speed n.

Draw the line CD perpendicular to the axis of abscissæ, and draw the line OP through P until it intersects this vertical line, making $PQ = E$. The point of intersection of OP and CD then represents the value of r_{sh} at the speed n. Now lay off on CD a scale of values of r_{sh}, taking the actual value of r_{sh} at speed n as unity.

Now suppose it is required to find the value of E for a speed $n' = n \div 1.2$. As a first step, imagine that the value of r_{sh} is increased from unity to 1.2, the speed meanwhile remaining constant. Under these conditions, we have $E' = Q'P'$. Now imagine this increased value of r_{sh}, and the original speed n, to be both decreased in the ratio 1.2:1. This would bring r'_{sh} back to its original value, and would reduce the value of E' (*i.e.* $Q'P'$) in the ratio 1.2:1. Therefore the required value of the generated e. m. f. at speed n' is $(1 \div 1.2)\, Q'P'$.

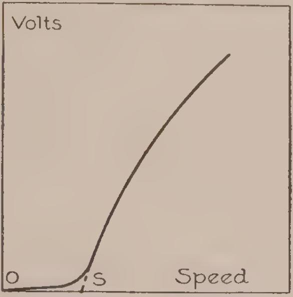


Fig. 162. Typical Voltage-Speed Characteristic of a Shunt Generator at Zero Current Output.

Fig. 162 shows a typical voltage-speed characteristic curve of a shunt generator at zero load. If it were not for the effect of residual magnetism, this curve would cut the speed axis at S. The speed corresponding to S is called the *critical speed* of the given shunt-wound generator; and when the speed is less than this value, it cannot build up at all.

The critical speed may be obtained from Fig. 161 by extending the line tangent to OA at O (*i.e.*, OB'), until it intersects CD produced, at a point which is equal to $n \div n''$; whence n'' is the critical speed.

Relation between Magnetization Curve and Total Characteristic Curve of a Shunt-Wound Generator. Let us assume OA as the magnetization curve of the machine in Fig. 163, the ordinates of the straight line OB representing the values of $V = r_{sh} I_{sh}$. Consider any given point P on OB. The abscissa OS is the shunt field-exciting current I_{sh}, and the ordinate SP is V. It remains to find the point P' on the total characteristic curve corresponding to P.

Let n be the number of turns of wire in the shunt field-winding, and let d be the number of demagnetizing turns on the armature, through each of which the entire armature current may be considered as flowing. Then the resultant field-excitation is $(nI_{sh} - dI_a)$* ampere-turns, which may be written $n\,(I_{sh} - I_a d \div n)$. It follows, then, that the actual resultant field-excitation and the actual value of E are such as would be produced by a field-exciting current equal to $I_{sh} - I_a d \div n$ acting alone; that is, the distance $Q\,P''$ is equal to $I_a d \div n$, P'' being the unknown point on the magnetization curve corresponding to P Furthermore, the ordinate of P'' is, of course, E, so that the distance QP is equal to $E - V = r_a I_a$. Now, as I_a is as yet unknown, but since we have $PQ = r_a\, I_a$, and $QP'' = I_a d \div n$, it is evident that the direction of PP'' is independent of I_a. In fact, the direction of PP'' may be once for all determined by laying off $PM = r_a I_a$ and $MN = I_a d \div n$ for any arbitrary value of I_a. The line PN then fixes the direction of PP'', and the point P'' is found at the intersection of PN and OA, as indicated.

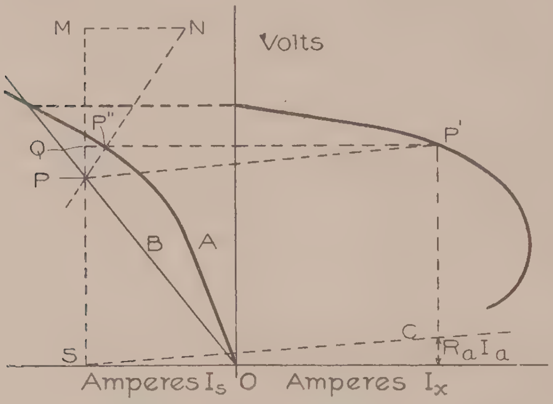


Fig. 163. Relation between Magnetization Curve of a Shunt Dynamo and Its Total Characteristic as a Generator.

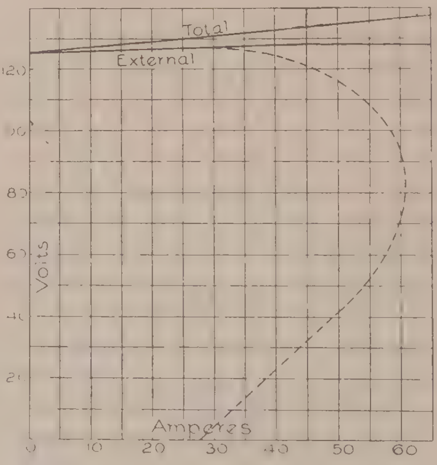


Fig. 164. Total and External Characteristic Curves of Compound-Wound Generator.

Having thus determined the point P'', the point P' on the total characteristic curve which corresponds to the chosen point P, lies on a horizontal line drawn through P'', and the abscissa of P' is determined by the condition that the corresponding ordinate of SC shall be equal to PQ $(= r_a I_a)$. The point P' thus determined is most easily located by drawing a line through P parallel to SC. Such a line will intersect the horizontal line through P'' at the desired point P'.

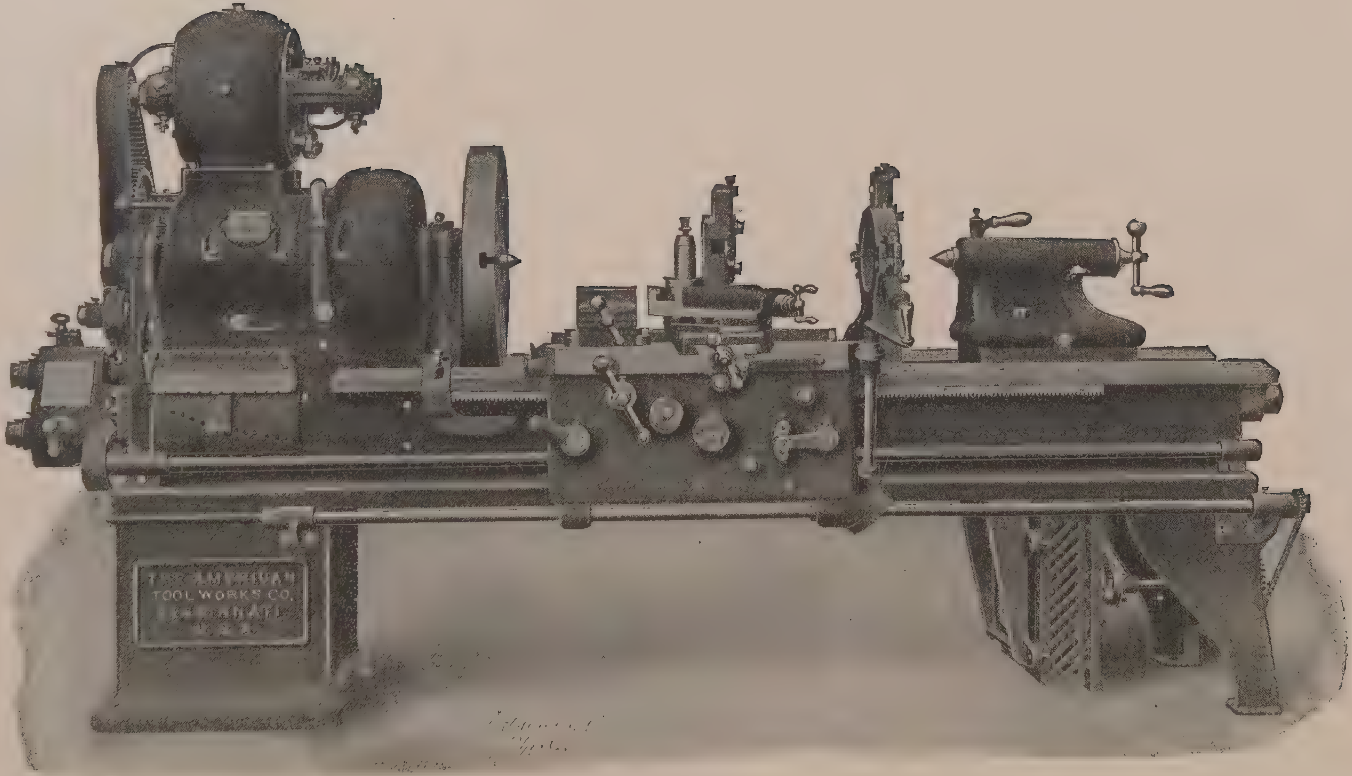
---

* The value of d is equal to $\frac{2\alpha}{360^\circ} \times \frac{Z}{c}$, where α is the angle of brush lead.

Characteristic Curves of Compound-Wound Generators. The compound-wound generator has heretofore been treated as a shunt dynamo to which series turns have been added to compensate for the internal drop, and to raise the terminal voltage with load if desired. Consequently there is no need now to discuss this type of generator minutely.

Fig. 164 shows the external and total characteristic curves of a typical over-compound-wound generator, the terminal voltage of which rises with increase of current up to and beyond rated load. The dotted portion of the curve shows the rapid fall of terminal voltage as the load is still further increased, resulting from the great demagnetizing action of the current in the armature and from the decrease of that part of the field-excitation which is due to the shunt field-exciting current.

The computation of the number of series turns has been previously given, so that nothing further remains to be considered.



MOTOR-DRIVEN AMERICAN ENGINE LATHE.

DIRECT CURRENT MOTORS.

GENERAL DISCUSSION.

It has been shown that by means of a **generator** mechanical energy is converted into the electrical form of energy. An electric **motor** is the reverse of this, that is, it converts electrical energy into the mechanical form of energy.

Fundamental Principle. We have learned that when a conductor which forms part of a circuit moves so as to cut lines of magnetic force, a current passes in the conductor, this being the principle of the generator. On the other hand, if a current of electricity passes through a conductor at right angles to lines of magnetic force, the conductor tends to move so as to cut them. This will be made clear by considering Fig. 1. The dots represent lines of magnetic force, their direction being upwards through the paper. *C* represents a conductor that is movable on the rails *A* and *B* which form part of the circuit. The current flowing through *C* causes it to move along the rails to the right or left according to the direction of the current. This is the fundamental principle of the motor.

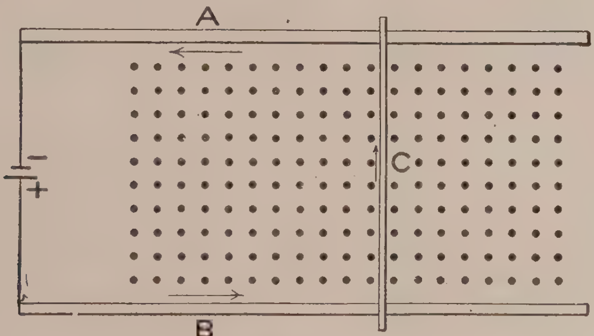


Fig. 1.

Thus we have a means of imparting mechanical motion to a body at the expense of electrical energy.

Direction of Motion. A simple method of obtaining the direction of motion when the direction of the current and of the lines of force are known, is by means of Fleming's rule. In finding the direction of the current in generators the *right* hand is used. In finding the direction of motion of motors the *left* hand is used. The thumb, forefinger, and middle finger of the left hand are held at right angles to each other; then if the forefinger shows the direction of the lines of force, and the middle finger the direction of the current, the thumb will show the direction of motion.

By applying this rule to the case shown in Fig. 1 it appears that the motion of C will be to the right. If the current was in the opposite direction C would move to the left. If the direction of the lines of force was downward through the paper, the direction of current remaining as represented, C would move to the left. If both the direction of current and lines of force were opposite to that represented in Fig. 1, then by the rule it is evident that the motion of C will still be to the right.

Interchangeability of Motors and Dynamos. There is essentially no difference between a motor and a dynamo. In fact dynamos usually may be run as motors or motors may be run as dynamos. If a current is passed through the armature of a dynamo we have the conditions for a motor, and the armature will rapidly rotate.

In view of these facts it is evident that nearly all that has been said in regard to generators, applies equally well to motors Therefore in this section it is only necessary to consider the special characteristics of the latter.

Motion of the Armature. Fig. 2 represents a ring armature which is supplied with a current of electricity from some external source. The direction of the lines of force of the field is from right to left. The direction of the current in a ring armature should be taken as that in the wire on the outside, because the wire on the outside of the ring cuts a greater number of lines of force than the wire on the inside of the ring. Nearly all lines pass through the armature core, as in Fig. 3.

Considering the right-hand half of the ring we see that the direction of the current in the winding on the outside is downward through the paper. By applying Fleming's rule, using the left hand, it is seen that the rotation of the armature will be left-handed. Now considering the left-hand half of the ring (the current in the winding on the outside being upward through the paper) the rotation of the armature is found to be left-handed. Hence each half of the armature causes a left-handed rotation.

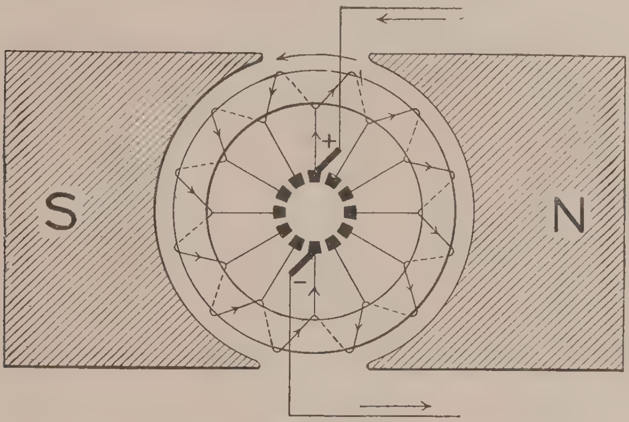


Fig. 2.

Reversal of Rotation. By reversing *either* the direction of the lines of force *or* the direction of the armature current, the direction of rotation will be reversed. If *both* the lines of force and the current are reversed the direction of rotation will be unchanged. These statements may be verified by the application of Fleming's rule to the different cases.

Therefore, the direction of rotation of a motor armature may be changed by reversing *either* the field of force *or* the armature current, but not both.

Generators Run as Motors. By applying Fleming's rule as to the direction of rotation of motors it is easy to determine in what direction the armature of a generator will rotate when run as a motor.

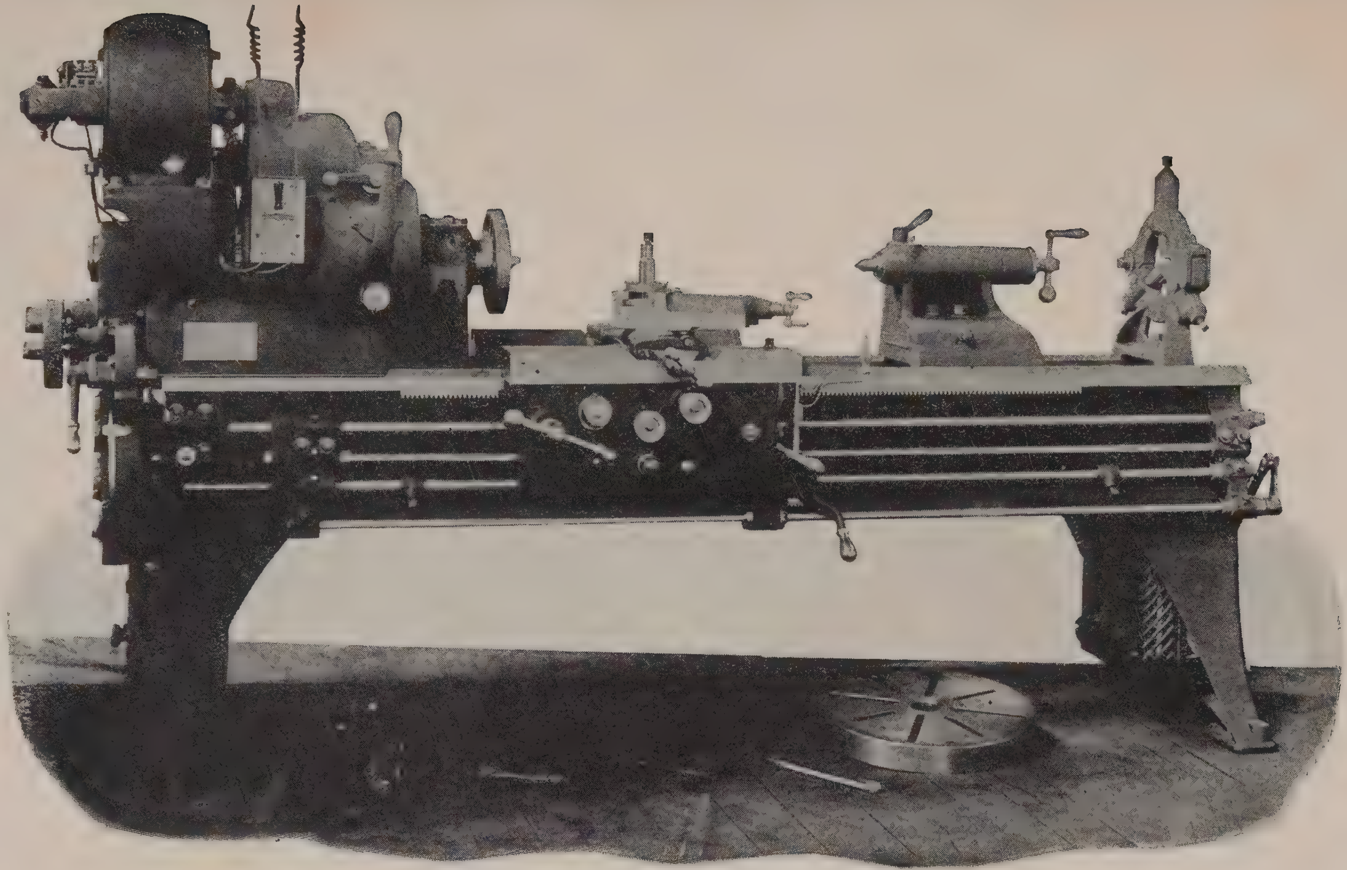
If a series generator is run as a motor the armature will rotate in the opposite direction to that in which it has been driven because both the armature and field currents are reversed; it is, therefore, necessary to reverse the brushes. If the original direction of rotation is desired then either the armature or field connections must be reversed.

The armature of a shunt generator will rotate in the same direction when run as a motor, because while the armature current is reversed the field current has the same direction as when run as a generator.

The armature of a compound generator will have its direction of rotation reversed when run as a motor if the series winding has a greater magnetizing effect than the shunt winding. The direction of rotation will remain the same if the magnetizing effect of the shunt coil is greater than that of the series winding. This will be understood when it is considered that in the generator the field excitation is that due to the *sum* of the magnetizing effects of the shunt and series coils, whereas when run as a motor it is their difference. Of course reversing the connections of either the series or shunt winding would then cause the field excitation to be that due to their sum, the direction of rotation depending upon which connections were changed. If the connections of the series coil were changed the direction of rotation would remain as before; changing the connections of the shunt coil would reverse the rotation.

Counter Electromotive Force. We have learned that when a conductor moves across lines of magnetic force, an E. M. F. is generated in the wire, and that this is the fundamental principle of the dynamo. Now, when the armature of a motor is caused to rotate, by passing a current through it, the very act of moving across the field of the motor causes the generation of an E. M. F. This E. M. F. is opposed to that applied to the motor and is known as the *counter* E. M. F.

The greater the speed of the armature, the greater will be this counter E. M. F., as a larger number of lines of force are cut in a given time. Also the greater the counter E. M. F. the less will be the drop of potential in the armature, for the effective E. M. F. is reduced as the counter E. M. F. increases. The strength of the armature current will therefore depend upon the speed. When the armature is forcibly restrained from rotating, the current is at its maximum, being equal to the E. M. F. applied at the brushes divided by the resistance. On releasing the armature, the strength of the current gradually decreases as the motor comes up to speed.



LATHE WITH SINGLE-VOLTAGE FIELD-WEAKENING MOTOR.

Controller Operated by a Handle on the Carriage.

Motor Equation. The drop of potential in a motor armature is equal to the applied E. M. F. minus the counter E. M. F. Hence from Ohm's law, we have,

$$I = \frac{E - e}{r}$$

where I is the armature current, E the E. M. F. applied at the brushes, e the counter E. M. F., and r the armature resistance. This is the fundamental *motor equation.*

From this equation it is evident that when e is small, that is, before the motor is up to speed, the armature current will be large. As the speed increases the counter E. M. F. is increased causing the current to become less and less until at full speed the current is normal.

Example. — The armature resistance of a motor is .54 ohm, the E. M. F. at the brushes is 215 volts, and the counter E. M. F. is 190 volts. What current passes through the armature?

Solution. — By the motor equation,

$$I = \frac{215 - 190}{.54} = 46.3 \text{ amperes (nearly).}$$

Ans. 46.3 amperes.

Example. — If the armature current is 14.1 amperes, the voltage at the brushes 109 and the armature resistance 1.69 ohms, what is the counter E. M. F.?

Solution. — Substituting in the motor equation,

$$14.1 = \frac{109 - e}{1.69}$$

$$e = 85.2 \text{ volts (approx.).}$$

Ans. 85.2 volts.

The Distortion of Field which occurs in a dynamo is also present in a motor, being due to the fact that the lines of force of the armature field are nearly at right angles to those of the field magnets, the amount of distortion being dependent upon the relative strength of the two fields.

In a motor the direction of the armature current and consequently the direction of its field is opposite to that in a dynamo. This causes the resultant field of a motor to be as represented in Fig. 3. It is evident that the neutral points are shifted *backwards*, whereas in the generator they are shifted forwards. This figure should be compared with the corresponding one for a dynamo, Fig. 35, in the section devoted to *Theory of Dynamo-electric Machinery.* Hence, to place the brushes at the neutral point of a motor they are shifted in an opposite direction to that of rotation. The greater the armature current the greater will be the distortion of field, and the more the brushes must be shifted backwards.

If the field magnets are made very powerful as compared with the armature, the distortion of field will be very slight or will be practically absent. In that case the brushes need not be shifted for variations in the load.

As seen in Fig. 3 the density of the lines of force is greater at the horns A, which the armature is approaching, than at the horns *B*, from which it is receding; consequently the induced Foucault currents and the heating will be greater in the horns *A*, while in the generator the heating is greater in the horns from which the armature is receding. In the case of the motor the air current tends to equalize the difference of temperature between the horns *A* and *B*, because cool air is drawn in at *A* and ejected somewhat warmer, at *B;* whereas in the generator cool air is drawn in at the cooler horns which tends to increase the difference of temperature.

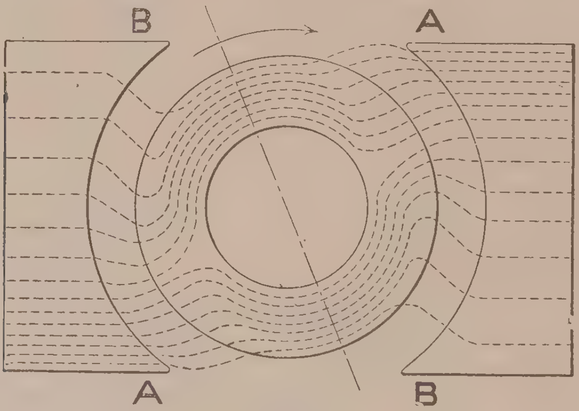


Fig. 3.

Efficiency. The *commercial efficiency* of a motor is equal to the actual output divided by the actual input, or

$$\textit{commercial efficiency} = \frac{\textit{output}}{\textit{input}}.$$

Or $$\textit{commercial efficiency} = \frac{\textit{input} - \textit{losses}}{\textit{input.}}.$$

The losses in a motor may be given under two heads:

The **electrical** losses,

(*a*) Armature wire I^2 R loss.
(*b*) Field wire I^2 R loss.

The **stray power** losses,

(*c*) Friction of bearings.
(*d*) Friction of brushes.
(*e*) Friction due to air resistance.
(*f*) Waste currents in coils during commutation.
(*g*) Foucault currents in armature core.
(*h*) Hysteresis in armature core.
(*i*) Foucault currents in armature wire.
(*j*) Foucault currents in pole pieces.

The electrical losses in the field and armature windings are due to the heating of the conductors by the current flowing through them. This loss as we have learned varies directly as the square of the current and as the resistance, that is, as $I^2 R$.

The stray power losses are small when considered separately, excepting friction of bearings, but collectively they usually amount to as much as the electrical losses. The stray power losses are practically constant for any load.

The *electrical efficiency* is the efficiency of the motor when only the electrical losses *a* and *b* are considered. This may be expressed as the input minus the electrical losses, divided by the input, or

$$\textit{electrical efficiency} = \frac{\textit{input} - \textit{electrical losses}}{\textit{input}}.$$

The electrical efficiency, therefore, only indicates the amount of the electrical losses and does not take into account the stray power losses.

The *efficiency of conversion* or *gross efficiency* of a motor is the ratio of the output to the useful electrical energy or to the input minus the electrical losses, that is,

$$\textit{gross efficiency} = \frac{\textit{output}}{\textit{input} - \textit{electrical losses}}.$$

The gross efficiency, therefore, takes into account only the stray power losses.

When no efficiency is specified, the commercial efficiency is understood.

The commercial efficiency of small motors ranges from 50% to 75%. Motors of from three to ten horse-power have efficiencies which range from 75% to 85 %. Larger motors should have an efficiency in the neighborhood of 90%.

Example.—A motor has at its terminals an E. M. F. of 220 volts, and takes a current of 26 amperes. The output is 5.94 horse-power; what is the efficiency of the motor?

Solution.—Input $= 220 \times 26 = 5720$ watts.

$$= \frac{5720}{746} \doteq 7.67 \text{ H. P. (approx.)}$$

$$\text{Efficiency} = \frac{5.94}{7.67} = .774 + \text{ or } 77.4 + \%$$

Ans. 77.4 + %

Siemens' Law of Efficiency. This law is as follows: The efficiency of a motor is equal to the ratio of the counter E. M. F. to the applied E. M. F.

This law assumes that the only loss existing is that in the armature wires, or $I^2 r$, where I is the armature current and r the armature resistance. Hence it is assumed that there are no stray power losses, and also that we have a magneto motor.

The proof of the law is as follows:

$$\text{Efficiency} = \frac{input—losses}{input}.$$

$$\text{Input} = E\,I.$$

$$\text{Losses} = I^2\,r.$$

Hence,

$$\text{Efficiency} = \frac{E\,I - I^2\,r}{E\,I}$$

$$= \frac{E - Ir}{E}$$

By the motor equation

$$I = \frac{E - e}{r}, \text{ then } Ir = E - e.$$

Therefore,

$$\text{Efficiency} = \frac{E - (E - e)}{E}$$

$$\text{or, Efficiency} = \frac{e}{E}.$$

That is, the efficiency is equal to the counter E. M. F. divided by the applied E. M. F.

Hence the greater the counter E. M. F. the higher the efficiency of the motor. If the counter E. M. F. could become equal to the applied E. M. F., the efficiency would be equal to unity, or 100 per cent, but in that case no current would pass in the armature and consequently there could be no output.

Jacobi's Law of Maximum Output. This law may be stated as follows: The maximum amount of work is done by a motor when the speed is such that the counter E. M. F. is one-half of that applied to the motor.

The proof of this law is most easily understood by the aid of a diagram. Fig. 4 represents a square having the length of the side equal to E, the applied E. M. F. The distance $A\ B$ is equal to e, the counter E. M. F. The diagonal is drawn from A, and the horizontal from B. At the point where this crosses the diagonal, a vertical is drawn. The distance $B\ C$ is evidently equal to $E - e$.

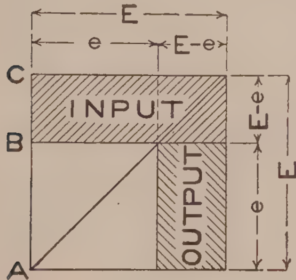


Fig. 4.

The input is equal to $E\ I$, and as

$$I = \frac{E - e}{r},$$

then

$$\text{input} = E\ I = \frac{E\,(E - e)}{r}.$$

The output is equal to the input minus the losses, that is,

$$\begin{aligned} \text{output} &= \frac{E\,(E - e)}{r} - I^2\,r \\ &= \frac{E\,(E - e)}{r} - \left\{ \frac{E - e}{r} \right\}^2 r \\ &= \frac{E\,(E - e) - (E - e)^2}{r} \\ &= \frac{e\,(E - e)}{}. \end{aligned}$$

In these values of output and input a constant, r, appears in the denominator of each, therefore the relation of the output and input will be as the magnitude of the numerators. That is, we may represent output by $e\ (E - e)$, and input by $E\ (E - e)$. Referring to the figure, it is evident that the area of the rectangle *output* is equal to $e\ (E - e)$; that of the rectangle *input* is equal to $E\ (E - e)$.

Now if in Fig. 4 the counter E. M. F. is decreased the output will increase until it becomes a square, and will evidently then have a maximum value as shown in Fig. 5. The counter E. M. F. is then one-half the applied E. M. F. Hence the maximum amount of work is done by a motor when the counter E. M. F. is one-half of that applied.

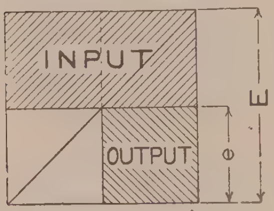


Fig. 5.

When a motor is doing a maximum amount of work the value of the current, as found by the motor equation, is one-half of that which would pass when the motor is at rest, that is, when no counter E. M. F. is generated.

It is evident from Fig. 5 that when the output is a maximum it is equal to one-half the input, consequently the efficiency is then 50%. This is also seen to be true from Siemens' law because e is one-half E, hence the efficiency is equal to 50%.

On account of the assumptions which must be made in the proof of these laws they are not strictly followed in practical machines.

Torque. The torque of a motor is its tendency to turn. It is usually expressed in pound-feet, and is equal to the pull in pounds exerted at one foot radius.

If it is known that a certain number of pounds pull is exerted at the circumference of a pulley whose radius is known, the torque is obtained by multiplying the pounds pull by the radius in feet. On the other hand, if the torque is known the pull at any radius is found by dividing by the radius.

The number of foot-pounds of work done by one revolution of a shaft is equal to the torque multiplied by $2\ \pi$, for $2\ \pi$ is the circumference in feet of a circle of one foot radius, and torque is the pounds pull at that distance, hence the product of the pounds pull and distance through which it acts gives the work done. If there are n revolutions per minute, the foot-pounds of work done per minute will be $2\pi n T$, where T is the torque; hence the horse-power will be

$$\text{H. P.} = \frac{2\pi n T}{33{,}000}.$$

If the horse-power and number of revolutions are known, the torque may be found from the formula

$$T = \frac{\text{H. P.} \times 33{,}000}{2\pi n}.$$

If the torque and the horse-power are known, the number of revolutions may be found from the formula

$$n = \frac{\text{H. P.} \times 33{,}000}{2\pi T}.$$

In a given armature, the torque varies directly as the product of the field strength and armature current, or

T *varies as* fI

where T is the torque, f the field strength, and I the armature current. That is, if the field is kept constant the torque will vary directly as the armature current, and if the latter is kept constant the torque will vary directly as the field strength.

Measurement of Torque. The Prony brake may be used to measure the torque of a motor. The arrangement is shown in Fig. 6. P is a pulley on the armature shaft; the blocks A and C bear against the face of the pulley, the pressure being regulated by the wing-nuts e. The lever L which is clamped to A, is counterbalanced by the weight w. The weight W which is supported by

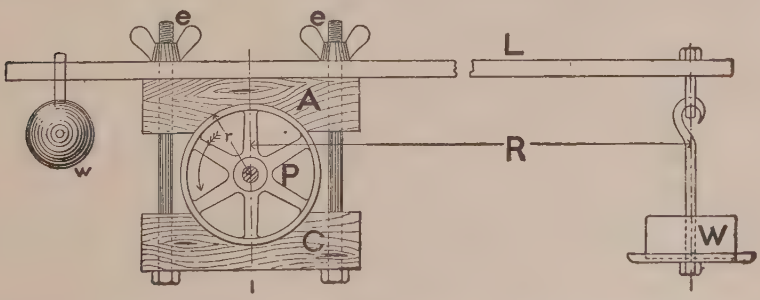


Fig. 6.

the lever has such a value as will keep the lever horizontal when the pulley is rotating.

To find the torque at a certain speed or when the motor take a certain current, the pressure on the pulley is adjusted until the speed or current is that desired. The weight W is made to balance the tendency of the lever to turn. The torque is then found by multiplying the measured distance R in feet, by the weight W in pounds.

Example.—In finding the output of a motor the distance R was 2.5 feet, the weight W was 12.4 pounds, and the number of revolutions of the motor was 1,400 per minute. What was the output of the motor in horse-power?

Solution.— Torque $= 2.5 \times 12.4 = 31.$ pound-feet.

$$\text{H. P.} = \frac{2\,\pi\,n\,T}{33{,}000}$$

$$= \frac{2 \times 3.14 \times 1{,}400 \times 31}{33{,}000}$$

$$= 8.25 +$$

Ans. 8.25 + H. P.

Example.— What pull at the rim of a pulley 10 inches in diameter will be given by a 6 H. P. motor running 1,200 revolutions per minute?

Solution.— $$\text{T} = \frac{\text{H. P.} \times 33{,}000}{2\,\pi\,n}$$

In this case H. P. $= 6$. $n = 1{,}200$.

Therefore

$$\text{T} = \frac{6 \times 33{,}000}{2 \times 3.14 \times 1{,}200} = 26.2 + \text{ pound-feet.}$$

But T = pounds pull × radius in feet.

$= \text{pounds pull} \times \frac{5}{12}$

Therefore pounds pull $= 26.2 \times \frac{12}{5} = 62.7$ lbs. (approx.)

Ans. 62.7 lbs.

Speed. To arrive at a general expression which will show upon what factors the speed of a motor depends, we shall make use of the motor equation,

$$I = \frac{E - e}{r}.$$

Let s represent the speed of rotation, a the number of conductors on the surface of the armature, f the field strength, and k

a constant. As the E. M. F. generated by an armature moving in a field depends upon the speed, number of conductors, and strength of field, the counter E. M. F. of a motor will be equal to

$$e = s\,a\,f\,k.$$

Substituting this value in the motor equation, we have

$$I = \frac{E - s\,a\,f\,k}{r} \quad \text{or} \quad I\,r = E - s\,a\,f\,k,$$

therefore $s\,a\,f\,k = E - I\,r$, and $s = \dfrac{E - I\,r}{a\,f\,k}$.

The armature resistance of a motor is usually very small, hence the product $I\,r$ would be small and may be neglected.

Therefore the expression for speed may be written

$$s = \frac{E}{a\,f\,k}.$$

From this expression it is evident that the speed varies *directly* as the E. M. F. applied at the brushes if the number of armature conductors and the field strength are constant. An increase in E causes a greater current to pass through the armature, which, acting upon the same field strength, causes an increase of speed, provided the torque exerted is kept constant.

If the number of armature conductors and the applied E. M. F. are constant, the above expression shows that the speed varies *inversely* as the field strength, that is, if the field is weakened the speed is increased or if the field is strengthened the speed is decreased. This is true for if the field is weakened the counter E. M. F. generated by the motor will be less allowing a greater current to pass in the armature. This will tend to increase the torque but if that is kept constant, the speed will increase, a higher speed being now required to generate the same E. M. F. as was the case when the field was stronger.

If the field strength and applied E. M. F. are constant, the speed varies *inversely* as the number of armature conductors, that is, a decrease in the number of armature conductors increases the speed. If a reduction is made in the number of conductors the motor must evidently run at a higher speed in order to generate the same counter E. M. F. as before, the torque being kept constant.

Windings of Motors. As in the case of a dynamo the common windings of a motor are shunt field winding, series field winding, and compound field winding.

The motor may be supplied with electrical power at a constant potential or the current may be constant.

SHUNT MOTORS ON CONSTANT POTENTIAL CIRCUITS.

Torque. As the torque of a motor with a given armature varies as the product of the armature current and field strength, if the field strength is constant the torque will vary directly as the strength of the armature current. The shunt motor on a constant potential circuit will have a constant current passing through the field coils, consequently the field strength will remain constant, and the torque will vary only as the strength of the armature current.

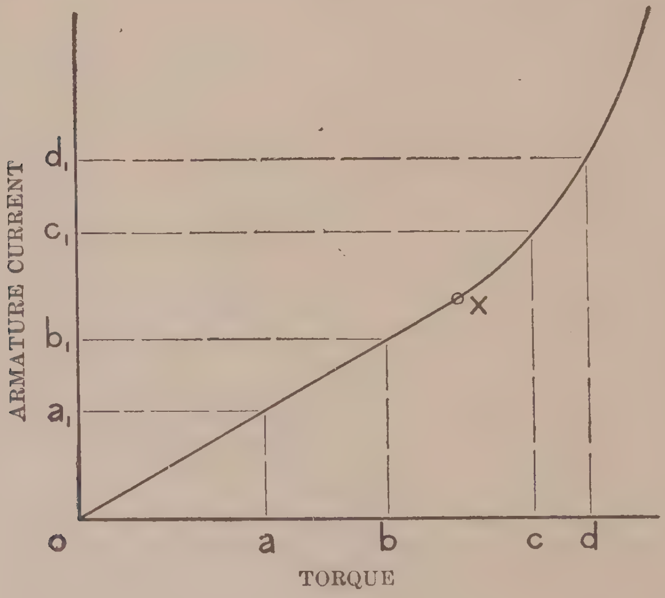


Fig. 7.

This is represented by the torque curve in Fig. 7. In this plot the abscissae *o a*, *o b*, *etc.*, represent the torque and the ordinates $o\ a_1$, $o\ b_1$, *etc.*, the armature current, that is, when the torque has a value represented by $o\ a$ the corresponding value of the armature current will be $o\ a_1$. It is evident that from o to the point x the plot is a straight line, an increase in the armature current causing a proportional increase in the torque. Beyond point x the line is curved this being due to distortion of field by the large armature current. Here a considerable increase in the current as $c_1\ d_1$ produces but a small increase $c\ d$ in the torque. A good machine should not have much distortion of field at or under normal load.

Constant Speed. The speed of a shunt motor on a constant potential circuit is practically constant for any load.

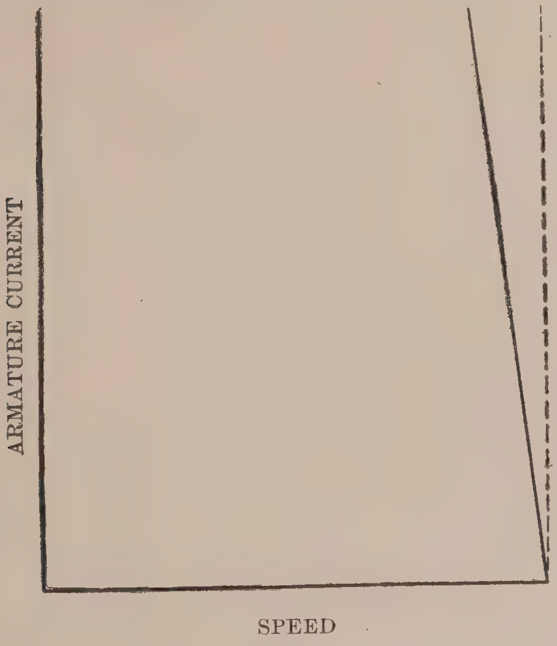


Fig. 8.

This is seen to be true from our approximate expression for speed,

$$s = \frac{E}{a\,f\,k}.$$

For since E is constant, f will be constant, and in a given armature a will be constant, therefore s will have a constant value.

As a matter of fact the speed will fall *slightly* as the torque increases. An increase of torque causes the armature current to be greater. As the applied E. M. F. is constant the increase in the armature current can only occur by decreasing the counter E. M. F., this being evident from the motor equation. Then if a decrease in the counter E. M. F. is necessary the speed must be slightly less.

This is represented in Fig. 8, which shows a gradually falling speed as the armature current is increased. In the figure, as indicated, the abscissae represent the speed, and the ordinates the armature current.

There are many methods of varying the speed of a shunt motor, all of which depend upon the variation of E. M. F. applied at the brushes, variation of field strength, or variation in the number of armature conductors. We will consider these methods in detail.

Variation of E. M. F. at the Brushes. We have seen that the speed of a motor varies directly as the E. M. F. applied at the brushes.

If a resistance is connected in series with the armature there will be a certain number of volts lost by the armature current passing through this resistance, consequently the voltage at the brushes will be less and the speed decreased. This method is illustrated in Fig. 9, the resistance *R* being inserted in the armature circuit. The commutator is represented by *C*, and the shunt field windings by F. The greater the resistance inserted the less will be the speed.

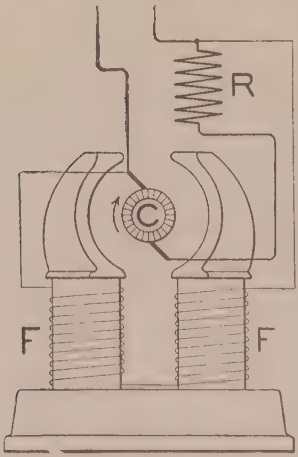


Fig. 9

Problem.—Suppose a shunt motor is to be used on a 220 volt circuit, the current taken by the armature at full load being 16 amperes and the speed 1,000 revolutions per minute. It is desired that the motor should run at $\frac{1}{2}$ speed when the torque is $\frac{3}{4}$ of that at full load. What resistance *R*, is it then necessary to insert in the armature circuit?

Solution. — Here $E = 220$, the normal current $I = 16$, and the speed $s = 1{,}000$ revolutions per minute.

We have seen that the expression for the speed of a motor is

$$s = \frac{E - Ir}{a\,f\,k},$$

and, as only the voltage E is to be varied, the denominator $a\,f\,k$ is a constant. Hence the formula may be written

$$s = \frac{E - Ir}{\text{constant}}.$$

As the resistance R is in series with r, and as r is very small we can neglect it. With R inserted the formula becomes

$$s = \frac{E - I\,R}{\text{constant}}.$$

The value of the denominator is easily found, for, when R is cut out of the circuit, $I\,R = 0$, and the speed is normal being 1,000 revolutions. Substituting these values in the equation we have

$$1{,}000 = \frac{220 - 0}{\text{constant}}$$

$$\text{constant} = .220.$$

Hence

$$s = \frac{E - I\,R}{.220}.$$

The torque is to be $\frac{3}{4}$ of that at full load, and as the field strength is constant the torque is decreased by decreasing the armature current I. Hence at $\frac{3}{4}$ torque the current will be $\frac{3}{4}$ of that at full load or $\frac{3}{4} \times 16 = 12$ amperes. The speed is to be $\frac{1}{2} \times 1000 = 500$ revolutions per minute.

Substituting these values in the preceding equation we obtain

$$500 = \frac{220 - 12\,R}{.220}.$$

Therefore $R = 9.17$ ohms nearly.

Ans. 9.17 ohms.

The above method of regulating the speed of a shunt motor is the one most largely used, being simple and perfectly controlling the speed at all loads. It has the disadvantage, however, of poor economy, because the energy lost as heat in the resistance is considerable, being equal to $I^2 R$.

The resistance used for starting the motor (see page 24) must not be used for regulating the speed in the above way. The starting resistance is usually very compact, and has a relatively small surface exposed to the air. It does not heat much during the short time required for starting, but if allowed to carry the armature current continuously it is liable to burn out. Regulating resistances are often made of zigzag strips of iron, insulated with asbestos, and exposed as much as possible to the air.

Variations of Field Strength. It has been shown that an increase in the speed of a motor is obtained by weakening the field strength, and that a decreased speed is obtained by increasing the field strength.

A simple and much used method of varying the field strength is the insertion or cutting out of resistance in the field circuit. This will change the current passing in the field coils and consequently the magnetization of the field magnets.

Another method of changing the magnetizing force is by having part of the field windings of German silver, and by cutting them in or out, the field strength is varied. As German silver has a high resistance the addition of these coils increases the resistance in greater proportion than the number of turns, so decreasing the ampere-turns. This method allows a moderate variation in speed, is easily operated, and is not expensive.

The objections to any method of regulating the speed by varying the field strength are:

1. If the speed is decreased the torque remaining constant, the motor gives out less power but requires at the same time an increased expenditure of energy in the fields.

2. It is customary in order to get the full power of a motor, to have the field magnets at or near the point of saturation at normal speed. But if it is desired to run the motor at a slower speed, the fields must be below their point of saturation at normal speed, since to decrease the speed the field strength must be increased. Hence at normal speed the fields are not worked to their full capacity, and the full power of the motor is not utilized. That is, the motor is larger than it otherwise would be, which means additional expense.

3. When the fields are weakened to increase the speed, the armature current causes greater distortion of the field and sparking is greatly increased.

If the resistance of the magnetic circuit is varied, the field strength will also be changed, and an increase of the magnetic resistance will cause an increase in the speed. This method of controlling the speed is not only usually difficult to apply but is also uneconomical. The magnetic resistance can be varied in three different ways: (*a*) the lines of force passing through the armature can be diverted through a movable piece of iron placed near the pole pieces, (*b*) the length of the air gap can be varied by having the relative position of field magnets altered, and (*c*) the cross section of the air gap can be varied by changing the relative position of the armature and pole pieces.

Variation of Number of Armature Wires. We have seen that the speed may be expressed approximately

$$s = \frac{E}{a f k}.$$

If the armature is arranged so that every two wires can be connected in multiple the number of conductors will then be equivalent to $\frac{a}{2}$ having $\frac{1}{2}$ the resistance. This change will cause the new speed s' to be double the speed s. For

$$s' = \frac{E}{\frac{a}{2} f k} = \frac{2\ E}{a f k},$$

which is twice the value of s.

If every two wires are again connected in multiple the number of conductors is $\frac{a}{4}$, the speed then being 4 s.

The same result is obtained in practice by changing two or more independent windings from series to multiple. These windings may be on the same armature core, or on separate cores on the same shaft, each winding requiring a separate pair of brushes.

The same result may be obtained by coupling separate motors to the same work.

Fig. 10 represents the changes where there are four independent armature windings or four independent motors. The separate commutators are represented by *c*, and field windings by *f*, the connections of the latter being the same for all speeds. In case *A* the brushes, and hence the armature windings are connected in series.

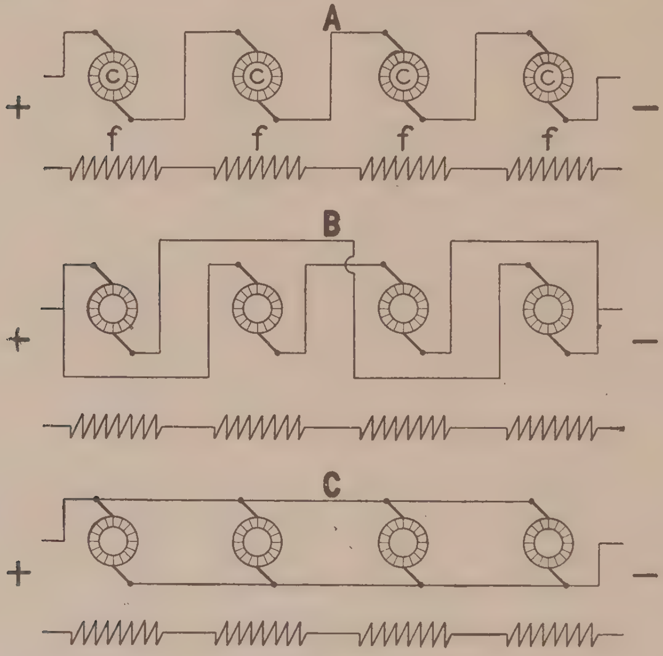
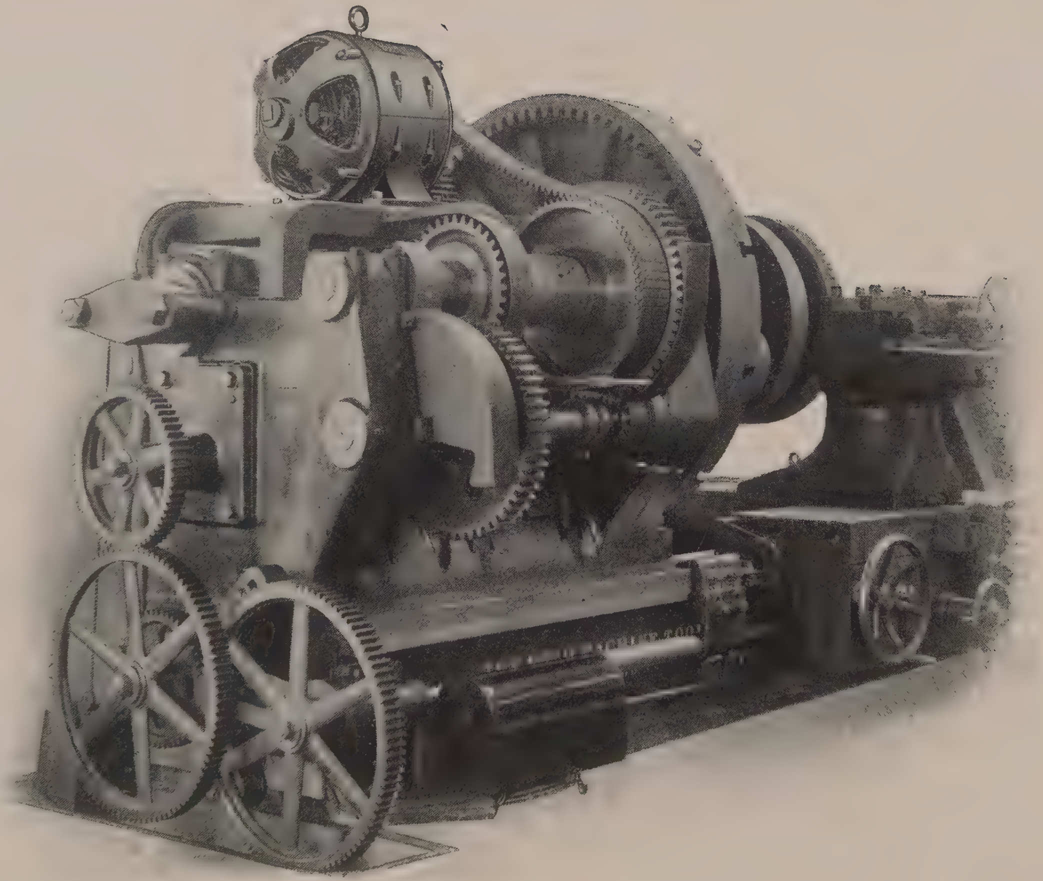


Fig. 10.

The number of armature windings being large the speed is small. In case *B* the armatures are connected in series multiple. The number of windings being then equivalent to $\frac{1}{2}$ of the number in the first case, the speed will be twice as great. In case *C*, the windings are all connected in multiple, hence the speed will be four times that in case *A*, and twice that in case *B*. We have, therefore, in case *C* full speed, in case *B* $\frac{1}{2}$ speed, and in case *A* $\frac{1}{4}$ speed.

This method of regulating the speed is satisfactory in regard to efficiency, for, if a constant torque is exerted by the motors



72-INCH LATHE DRIVEN BY 15 H.P. THOMPSON-RYAN MOTOR.

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throughout the above changes, the current taken by each motor will have a constant value. Hence in case B the current used will be twice that in case A; but in the former case the speed is twice as great, and although the energy consumed is twice as much, the output is also double. Therefore the efficiency remains unchanged. Similarly the efficiency remains unchanged in case C.

The objection to this method is, of course, the use of several motors, which involves extra expense.

Variation of Position of the Brushes. By shifting the brushes from the neutral point the speed of the motor can be increased. This will be understood from Fig. 11.

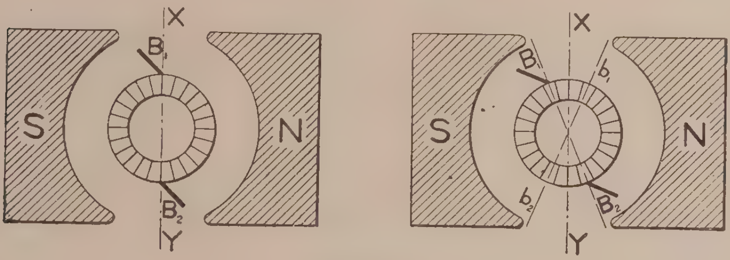


Fig. 11.

The neutral line is represented by $X\ Y$, and in the left-hand figure the brushes B_1 B_2 are at the neutral point, the entire counter E. M. F. generated, that is, by the conductors from B_1 to B_2, being effective. In the right-hand figure the brushes are shown shifted and in this position the effective counter E. M. F. is reduced. In this case the counter E. M. F. generated by the conductors from B_1 to X opposes that generated from X to B_2, the effective counter E. M. F. being reduced to that generated by the conductors from b_1 to B_2, and likewise from b_2 to B_1. For constant torque, however, the armature current must be constant when the field strength is not changed, therefore the counter E. M. F. must not be reduced. As a smaller number of conductors are now available to generate the counter E. M. F., the speed of the motor must be increased. That is, by shifting the brushes from the neutral point the speed is made higher.

This method is really equivalent to reducing the number of armature conductors. It has the great objection of causing excessive sparking and of being injurious to the commutator, brushes, and armature winding.

Starting Resistance. If a motor armature is restrained from rotating the current passing through it will be very large, being equal to $\frac{E}{r}$, since no counter **E. M. F.** is generated. This excessive current would damage the armature, hence it is necessary to have a large resistance in the armature circuit to make the current small while the motor is coming up to speed. That is, before starting a motor, a large resistance should be connected in the armature circuit which is gradually reduced as the motor comes up to speed.

In order not to have the armature current in starting larger than the normal current, the resistance inserted, R, should be $R = \frac{E}{I}$, where E is the applied E. M. F. and I the normal armature current. For motors of more than 15 horse-power, however, R should be greater than $\frac{E}{I}$ in order not to throw a heavy load suddenly on the driving dynamo.

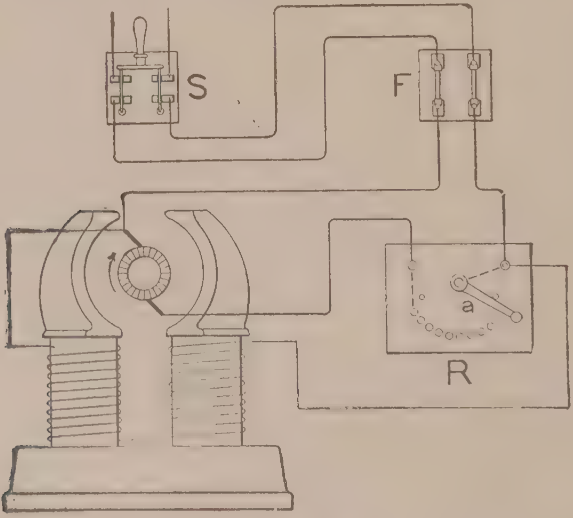


Fig. 12.

Connections. The connections for a shunt motor on constant potential mains are shown in Fig. 12. From the mains the conductors lead to the double pole switch S. The fuses F, made of an easily fusible metal, are placed on both lines to protect the motor from dangerous currents caused by short circuits. The fuses are of such a cross section that they melt when a current greater than the safe one for the motor passes through them, and so break the circuit. The starting resistance is R, and is arranged so that turning the arm a will close the armature circuit inserting the full resistance R, and then gradually reduce it until it is all cut out. The switch S is placed outside the other connections so that when it is opened they are entirely disconnected and may be handled without fear of receiving a shock.

Starting. After making sure that the arm of the starting resistance is in the position so that the armature circuit is disconnected, the switch S is closed, and the fields then become fully charged before any current flows through the armature. The armature circuit is then closed through the resistance R, and as the motor speeds up this resistance is gradually cut out. As the speed of the motor increases, the counter E. M. F. becomes greater and the armature current less, allowing the resistance R to be cut out.

Stopping. In stopping the motor the switch S is first thrown. After the motor has come to rest the arm a of the resistance is then turned to the position ready for starting.

While coming to rest the motor runs as a generator and the field current is supplied by the armature. The direction of this current being the same as before, its strength will *gradually* decrease as the motor slows down, thus allowing a *gradual* decrease in the field strength.

If the armature circuit is broken first, then on throwing the switch S the field current is cut off abruptly, and the high E. M. F. caused by self-induction produces a destructive flash at the switch; moreover a very high potential is produced in the field winding and this is likely to pierce the insulation. Also for this reason the switch should not be closed unless the motor is afterwards started.

Reversing Motors. Motors are reversed in the direction of their rotation by simply changing the relative direction of the magnetic field and the armature current. This, as we have seen is accomplished by changing *either* the direction of the armature current *or* the field current. The former is the more common method. A motor which is to be often reversed should have powerful field magnets so that there will be practically no distortion of the field, and no lead will be necessary for the brushes. Otherwise the lead would have to be changed when the rotation is reversed.

Reversing While Running. If the direction of the armature current is reversed while the motor is running, then until the armature comes to a stop and its rotation reversed, the counter E. M. F. acts *with* the applied E. M. F. This would cause the armature current to be extremely large being equal to

$$I = \frac{E + e}{r}.$$

It is therefore necessary that a large resistance R should be inserted in the armature circuit before the current is reversed. Then before the armature stops rotating the current will be

$$I = \frac{E + e}{R + r}.$$

However, as the direction of the armature current is now changed and comparatively large, the armature is quickly brought to rest, the current gradually decreasing as e becomes less and less.

When e becomes zero, that is, when the motor has stopped,

$$I = \frac{E}{R + r}.$$

The motor now speeds up in the opposite direction, e gradually increasing but now opposing E. As the motor speeds up, R is cut out, and the current becomes normal being equal to

$$I = \frac{E - e}{r}.$$

Reversing the direction of the current in the field circuit does not produce so abrupt a change in the motion of the armature, nor does its current become so excessively large. This is so because the field strength does not rise rapidly on account of self-induction and reluctance of the magnetic circuit, the armature then has time to slow down considerably so that the additive e is small, The reversing of the field circuit however, causes severe sparking at the switch contacts as well as being likely to injure the field wire insulation.

A motor should never be reversed while running unless in the most necessary cases, and then not without inserting in the armature circuit the full resistance.

Reversing Connections. In Fig. 13 is shown a common form of reversing switch. The two metal bars *H* are pivoted one at *a*, and one at *b*. A strip *K* of insulating material joins the two bars. In the position shown the wire *A* is positive and *B* is negative. When the bars are switched to contacts *c* and *d* in the position indicated by the dotted lines, wire *B* then becomes positive and *A* negative.

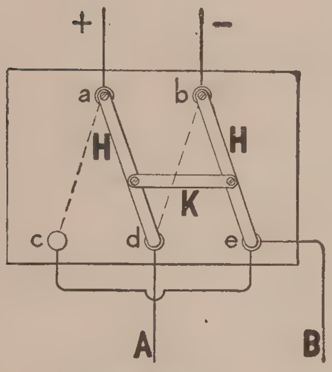


Fig. 13.

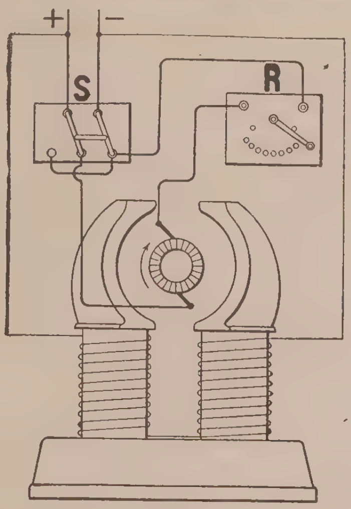


Fig. 14.

Fig. 14 shows the connections when a reversing switch *S* is inserted in the armature circuit of a shunt dynamo, the starting resistance being *R*. The reversing switch is sometimes combined with the starting resistance.

Maximum Output of Shunt Motor. We have seen that the maximum output of a motor when the only loss considered is that in the armature wires, is obtained when the armature current is $I = \frac{1}{2}\frac{E}{r}$; that is, when the strength of the current is one-half of that which would flow if the armature was restrained from rotating, the counter E. M. F. being equal to $\frac{1}{2} E$.

Since the stray power and field wire loss for a shunt motor on a constant potential circuit are approximately constant for any load, the loss in the armature winding is the only variable loss. For this reason Jacobi's law is also true for the commercial shunt motor.

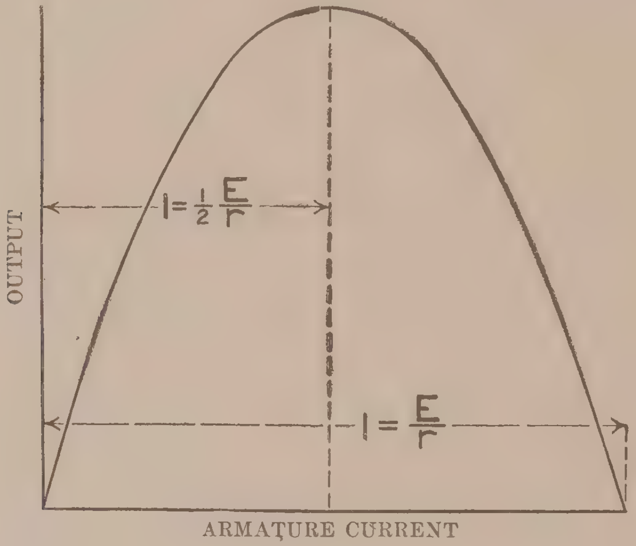


Fig. 15.

Fig. 15 shows the variation of the output with the armature current. At the beginning of the curve the current is zero, hence there could be no output. When the output has risen to its highest value, then $I = \frac{1}{2} \frac{E}{r}$ and $e = \frac{1}{2} E$. With a further increase in the current the output decreases until when $I = \frac{E}{r}$ the counter E. M. F. must be zero, that is; the motor is at rest and the output is zero.

Efficiency. Siemens' law of efficiency, $\left\{ \text{efficiency} = \frac{e}{E} \right\}$ is not closely followed by the commercial motor, since when the stray power and field wire loss is also taken into account, the efficiency will evidently be less than $\frac{e}{E}$.

It can be shown mathematically that the commercial efficiency of a shunt motor will be a maximum when the armature current has such a value that its square is equal to

$$\frac{\text{field wire loss} + \text{stray power loss,}}{\text{armature resistance}}$$

$$\text{or} \qquad I^2 = \frac{i_1^2 r_1 + S.\,P.}{r}$$

where i_1 is the field current and r_1 the resistance of the field winding.

The variation of the commercial efficiency of a shunt motor with a change in the armature current is shown in Fig. 16. It is seen that the efficiency rapidly rises with an increase in the current to its maximum value, and decreases more slowly as the current is further increased. When the efficiency is a maximum, the value of the current indicated by a in the figure is equal to

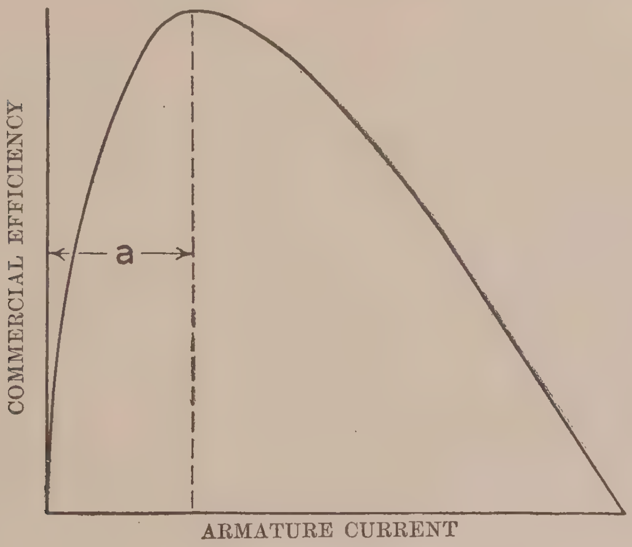


Fig. 16.

$$\sqrt{\frac{\text{field loss} + \text{stray power}}{\text{armature resistance}}}$$

Advantage and Disadvantages of Shunt Motors. The great advantage of shunt motors is that their speed is practically constant.

The disadvantages are as follows:

1. The torque increases only in proportion to the armature current since the field strength is constant.

2. There is a high potential between the terminals of the field winding.

3. Opening the field circuit suddenly, causes a large spark and a high potential due to self-induction.

4. The many turns of fine wire of the field coils involve extra expense since fine wire costs more per pound than coarse, the labor of winding is considerable, and a large amount of insulation is necessary.

5. Where shunt motors are run intermittently it is customary to keep the field coils constantly charged, the motor being started and stopped by closing and opening the armature circuit through the resistance. Keeping the fields charged when the motor is not in use is of course a loss of energy.

Uses of Shunt Motors. A constant speed is of the greatest importance in some classes of work, and this advantage makes the use of shunt motors very extended.

Shunt motors are used in machine shops, factories, and to run printing presses, pumps, elevators, etc., or in general where good speed regulation is required.

SERIES MOTORS ON CONSTANT POTENTIAL CIRCUITS.

Torque. In the series motor the same current passes successively through the armature and field windings. We have seen that the torque depends upon the armature current and the field strength, or

$$T \text{ varies as } I f.$$

An increase in the current strength of a series motor greatly increases the torque because (*a*) the armature current is increased, and (*b*) the field strength is also increased by the larger field current. Hence in series motors the torque increases as the square of the current. Therefore on light loads the current is small and the torque is small, and on heavy loads the current being large, the torque exerted is large. The torque increases as the square of the current, however, only when the fields are below their point of saturation. When near this point an increase in the current produces but a slight increase in the field strength, and the torque will then vary as the current strength only.

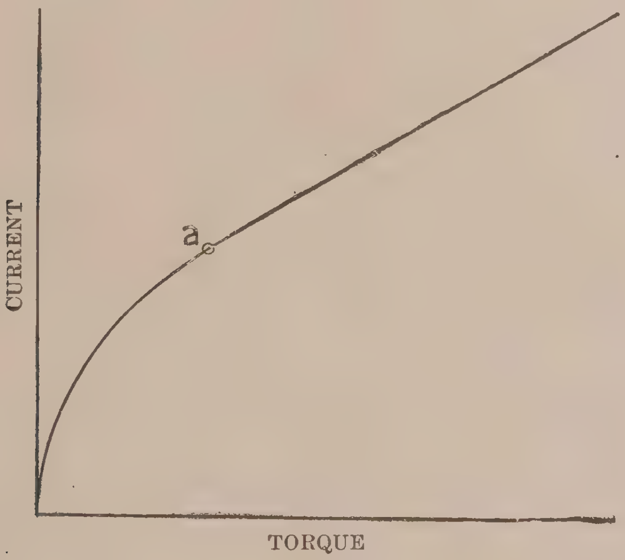


Fig. 17.

The curve in Fig. 17 shows the relation between the current taken by a series motor and the torque. Up to the point *a* the line has a considerable curve because the fields being below saturation, the torque increases as the square of the current. Beyond point *a* the fields are saturated and the torque then varies as the current only, the curve becoming a straight line.

Speed. In the case of shunt motors it was seen that the speed is nearly constant for all loads. In series motors the speed varies with the load. If part of the load is taken off of a series motor, the current becomes less, the fields are weakened, and this causes a large increase in the speed. If the load is entirely removed the speed becomes dangerously high.

Fig. 18 shows the speed curve for a series motor. It is evident from this curve that with a small current, or light torque on the motor, the speed is very large; with a large current the speed is small.

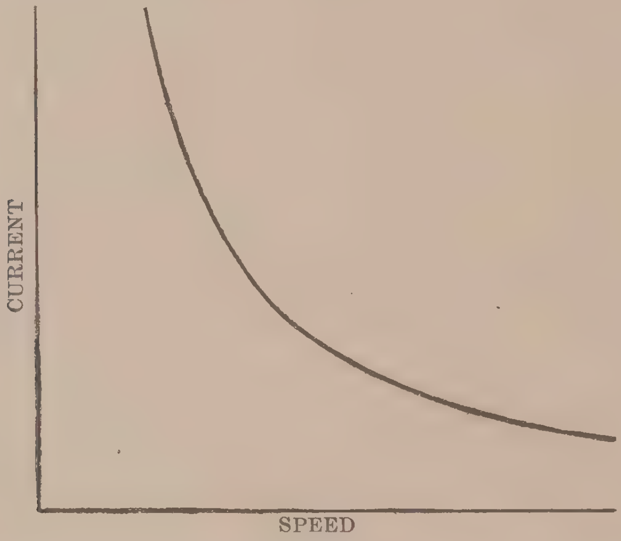


Fig. 18.

Speed Control of Series Motors. Series motors on constant potential circuits may have their speed controlled in a similar manner to that of shunt motors, there being some differences however, on account of the different field winding.

Variation of E. M. F. at the Brushes. This is the most common and most satisfactory method of controlling the speed. Fig. 19 illustrates this method, the resistance *R* being inserted to reduce the voltage available at the brushes, and consequently the speed. The current passes successively through the adjustable resistance *R*, the armature, and the field winding.

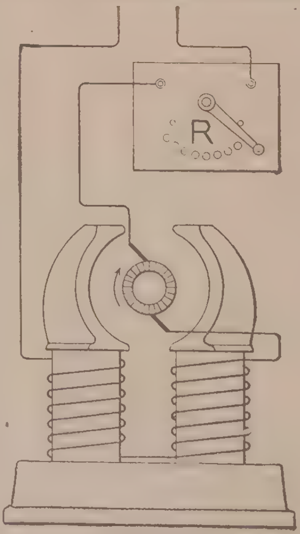


Fig. 19

Variation of Field Strength. The field strength can be varied in several ways. If the field winding is changed from a series coil to several coils in multiple the number or ampere-turns, and hence the magnetization will be reduced, causing the speed to be increased. Also cutting out turns or shunting a part of the field current through a by-path having an adjustable resistance will cause the speed to be increased. The latter method cannot be used for shunt motors, since the field winding is itself a shunt across the main circuit; but for series motors this method is a very useful one.

The resistance of the magnetic circuit may be varied as in shunt motors but this method is little used.

Other Methods. As in the case of shunt motors the speed of series motors may be varied by a change in the number of armature wires, as by coupling in series or multiple, and also by varying the position of the brushes. To obtain a very large range of speed there may be combinations of two or more methods.

Constant Speed. Nearly constant speed with varying load can be obtained with series motors by overwinding the field coils, that is, they may be wound so that the fields have their full strength when only one-half or even one-third of the normal current is passing. Hence with perhaps one-third load or more the fields will have a constant strength and the speed will be constant as in the case of the shunt motor. At full load the field current will be far greater than is necessary to saturate the magnets and consequently the efficiency is considerably lessened.

Starting. On starting, a rush of current tends to occur with this type of motor similar to that in case of the shunt motor; it is somewhat less however, because the field coils are in series with the armature and their resistance and self-induction reduce the excessive flow. A starting resistance is used as in the shunt motor, but can be considerably less.

Connections. These are very simple for a series motor and are indicated except the main switch and fuses, in Fig. 19; the same current passing successively through the starting resistance, armature and field winding.

Motors having more than two poles sometimes seem to have very complicated connections. Fig. 20 represents the connections for a four-pole series motor, and Fig. 21 for a four-pole shunt motor. By tracing out the connections the figures will be readily understood.

Reversing Series Motors. What has been said in regard to reversing shunt motors applies in general to series motors on constant potential circuits. Reversing while running is not so harmful to the latter as they are brought to rest sooner, since the excessive current passing through the field coils increases the field strength.

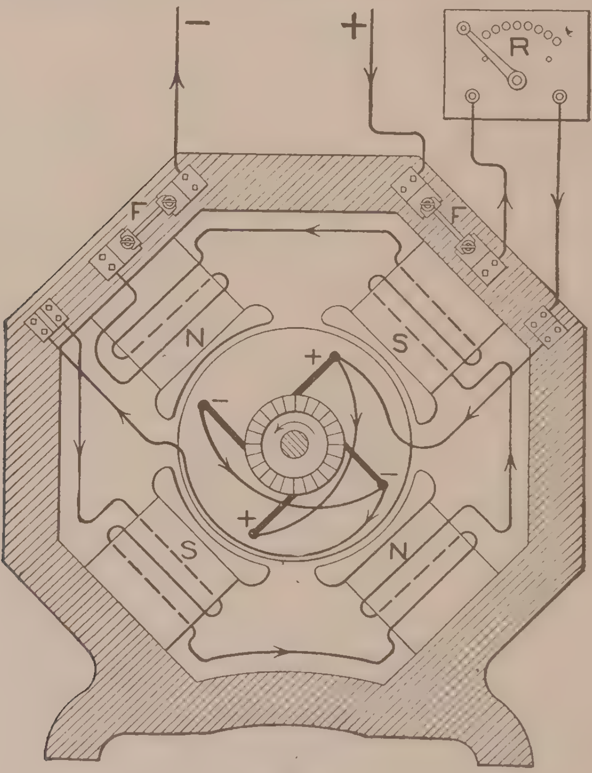


Fig. 20.

Advantages and Disadvantages of Series Motors. The advantages are:

1. The torque on overload is large; series motors are therefore well adapted for starting loads with great friction of repose.

2. The cost of the field coils is considerably less than in the case of shunt motors as the number of turns required is very much less.

3. The field coils and armature being in series one switch serves to cut out both at once.

The disadvantages are:

1. The speed varies with the load.

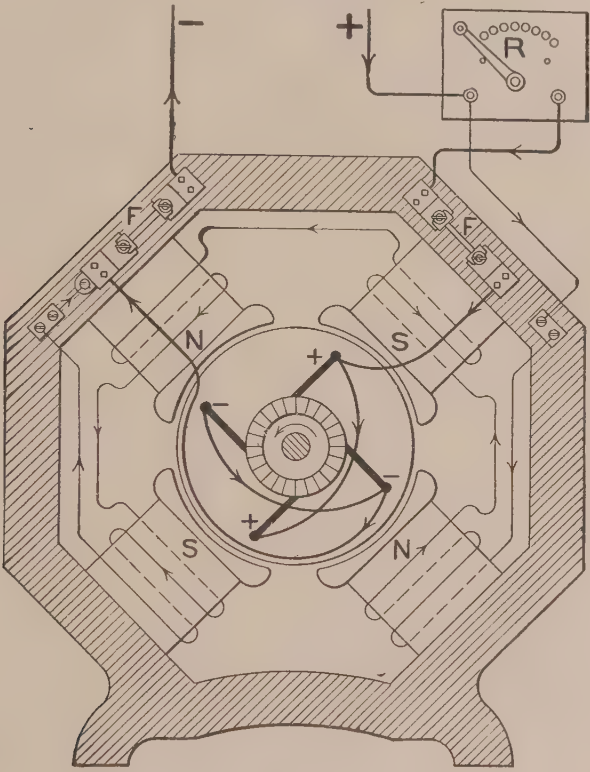


Fig. 21.

2. If the load is removed the speed becomes dangerously high and the motor may tear itself apart.

Uses of Series Motors. The most common use of this motor is in the electric railway where it is usually run on a 500 volt circuit. It is also used in operating hoists, mining machinery, and in general where the load cannot be entirely removed, where the starting torque required is large, and where a constant speed is not necessary.

COMPOUND MOTORS ON CONSTANT POTENTIAL CIRCUITS.

Compound Motors. The compound motor has two independent field windings; a shunt winding gives the main magnetization, and a series winding serves to regulate or to allow starting under heavy load.

Cumulative Compound Motor. This motor has the direction of the current in the series winding the same as that in the shunt winding and hence increases the field strength.

Such a motor has the advantage of a large torque on starting as in the case of a series motor, and an approximately constant speed as with the shunt motor. On starting the series coil is in the circuit, but is cut out when the motor has attained its full speed.

Use of Cumulative Compound Motor. The special use of this motor is where it is frequently stopped and started under a heavy load, and a nearly constant speed is desired.

Differential Compound Motor. The series winding in this motor has its current passing in an opposite direction to that in the shunt coil and consequently reduces the magnetization.

This motor gives a more constant speed than the simple shunt motor. We have seen that the speed of the shunt motor decreases *slightly* as the load increases; therefore if the field strength can be weakened with an increased load the speed can be kept up. The current in the series winding is greater the greater the load, hence the magnetization is reduced, and almost perfect speed regulation can be obtained.

It is necessary that the series coil should be inserted *after* starting the motor; otherwise its excessive current would weaken the fields so much that the starting torque would have hardly any value.

The differential motor has the serious disadvantage that with a large overload owing to the excessive current in the series coil, the field magnets may become demagnetized, and instead of the motor keeping up its speed it slows down or stops and is liable to burn out.

Use of Differential Compound Motor. Where a very constant speed is required this motor is used. The shunt motor, however, has a speed which is uniform enough for most purposes, and the differential motor is not much used now.

MOTORS ON CONSTANT CURRENT CIRCUITS.

Motors are now in use on constant current circuits to only a small extent. They cannot be made self-regulating, and therefore all have some form of mechanical governor to regulate the speed or torque. Another objection is the usually high potential of the circuits, this being a source of considerable danger.

Owing to the very general introduction of constant potential circuits, and the advantage of constant potential motors over motors which are not self-regulating, the latter have been largely superseded by the former.

Series Motors. The series wound motor is usually the type used on constant current circuits. As a constant current passes through the field and armature windings, the field strength and armature current will have a constant value and consequently the torque will be constant. Hence if the load is reduced the torque exerted remaining the same, the motor will speed up. If the load is entirely removed the speed becomes dangerously high, being much worse than when on a constant potential circuit for in the latter case the armature current is reduced as the speed increases. This increased speed can be prevented if the field is weakened, since the torque is then decreased, the armature current remaining the same.

The motor can be overloaded or held still without its being injured as the current is always the same, therefore no starting resistance is necessary and the throwing of a single switch starts or stops the motor.

Regulation. The usual method of changing the field strength to obtain constant speed is by cutting in or out turns of the field coils. The switch which does this is operated by some form of centrifugal governor, a slight increase of speed causing turns to be cut out and a slight decrease causing them to be inserted.

Another method is by rotation of the brushes. To reduce the field strength the brushes are rotated in a direction such that its magnetization will oppose that of the field magnets. To give a close regulation a comparatively large regulator is required.

MOTOR-GENERATORS.

Motor-generators, or dynamotors commonly called, are nearly synonymous terms applying to a combination of the *direct* *current* generator and motor, for the purpose of either increasing or decreasing the voltage of distribution.

The motor which drives the generator, is usually shunt-wound and is connected on constant potential mains.

The simplest case is where the motor is directly connected to the generator, the E. M. F. generated by the dynamo being available for any purpose. Such an arrangement allows a considerable variation of E. M. F. This is usually accomplished by inserting varying resistances in the field circuit of the dynamo; weakening the field, of course decreasing the volts generated.

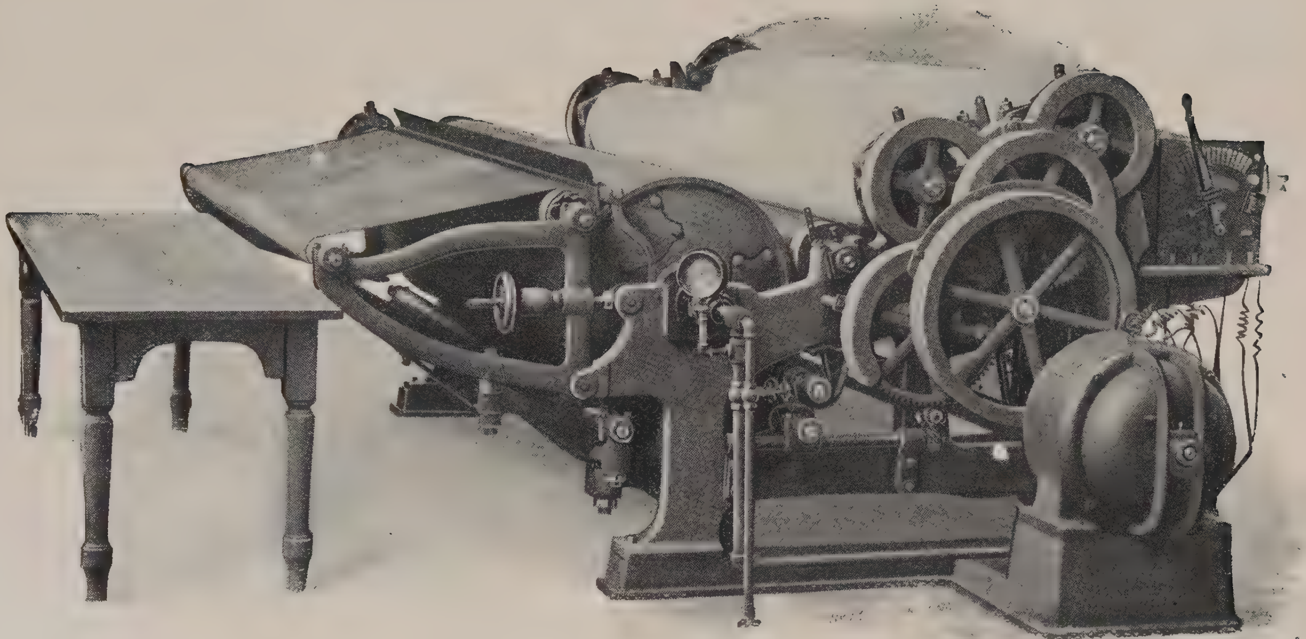
Where the ratio of transformation of voltage is definite, one field may be common to both motor and dynamo. The armature has independent motor and generator windings which have separate commutators. As the field is common to both the only method of varying the E. M. F. of the dynamo is by inserting resistances in either armature circuit or by shifting the brushes.

CALCULATION OF ELECTRIC MOTORS.

As a direct current dynamo may be used either as a generator or motor, it is evident that the principles of construction and calculation of direct current generators apply equally well to that of motors. Hence for the calculation of an electric motor it is only necessary to determine the corresponding values for a generator at the required speed, and to then proceed as in the calculation of a generator.

The question arises as to what power must the motor be calculated for when considered as a generator. We have seen that the losses in a dynamo are the electrical and the stray power. In a generator the output is equal to the total electrical energy less the *electrical* losses. In a motor the output is equal to the total electrical energy, which is the input, less *all* the losses, that is, the electrical together with the stray power loss. Hence, in making the calculations of a motor we must allow for the stray power loss and figure a generator which at the given speed has an electrical activity in watts equal to

$$\frac{\textit{motor output}}{\textit{gross efficiency}}.$$



FULLY ENCLOSED MOTOR

Driving Hercules Laundry Mangle.
Triumph Electric Company.

Small motors up to 5 horse-power have a gross efficiency of from 80% to 85%, that of motors from 5 to 20 horse-power ranges from 85% to 90%, from 20 to 300 horse-power ranges from 90% to 95%, and motors of more than 300 horse-power have a gross efficiency slightly above 95%.

The E. M. F. for which the generator is to be calculated is the *counter* E. M. F. of the motor, being the E. M. F. generated by the motor at the given speed. This from the motor equation is equal in the case of the shunt motor to

$$e = E - I r,$$

where e is the counter E. M. F., E the applied E. M. F., I the armature current, and r the armature resistance.

For the series motor

$$e = E - I (r + r_1),$$

where r_1 is the resistance of the field winding.

As the value of the resistances and current are not known, e must be estimated from values obtained by experience. The percentage of the applied E. M. F. which is lost in the armature, or in the case of the series motor in the armature and field winding, varies greatly according to the size of the machine. For shunt motors the per cent of the applied E. M. F. which is lost in the armature, is approximately as follows:

Up to ¾ H. P.	15 %
Up to 1½ H. P.	10 %
Up to 3 H. P.	8 %
Up to 7 H. P.	6 %
Up to 15 H. P.	5 %
Up to 35 H. P.	4 %
Up to 75 H. P.	3½%
Up to 150 H. P.	3 %

For motors of a greater output than 150 H. P. the per cent lost may be a little less. In the case of series motors the volts lost in the armature and field winding may be found by taking about twice the above percentage.

Having determined the electrical activity and the voltage for which the motor is to be calculated. the current capacity is found by dividing the former by the latter.

Example.—It is desired to construct a shunt motor which is to have an output of 5 H. P. at a speed of 1,200 revolutions per minute, the motor to be run on a 110 volt circuit. Determine the values of the quantities to be used when calculated as a generator.

Solution.—For a 5 H. P. motor the gross efficiency is taken to be 85%. The watts generated by the armature are to be, therefore,

$$\frac{5 \times 746}{.85} = 4{,}400 \text{ watts (approx.).}$$

Allowing 7% of the applied E. M. F. to be lost in the armature, the voltage to be generated, that is, the counter E. M. F., will be

$$110 \times .93 = 102 \text{ volts (approx.).}$$

The current capacity will, therefore, be

$$\frac{4{,}400}{102} = 43 \text{ amperes (approx.).}$$

Hence the armature is to be designed to generate a total E. M. F. of 102 volts, at a speed of 1,200 revolutions per minute, the current capacity to be 43 amperes.

Example.—Suppose we wish to design a series motor for a 220 volt circuit, the output to be 10 H. P. at 900 revolutions per minute. How is the machine to be designed?

Solution.—Supposing the gross efficiency to be 88% the number of watts to be generated is

$$\frac{10 \times 746}{.88} = 8{,}500 \text{ watts (approx.).}$$

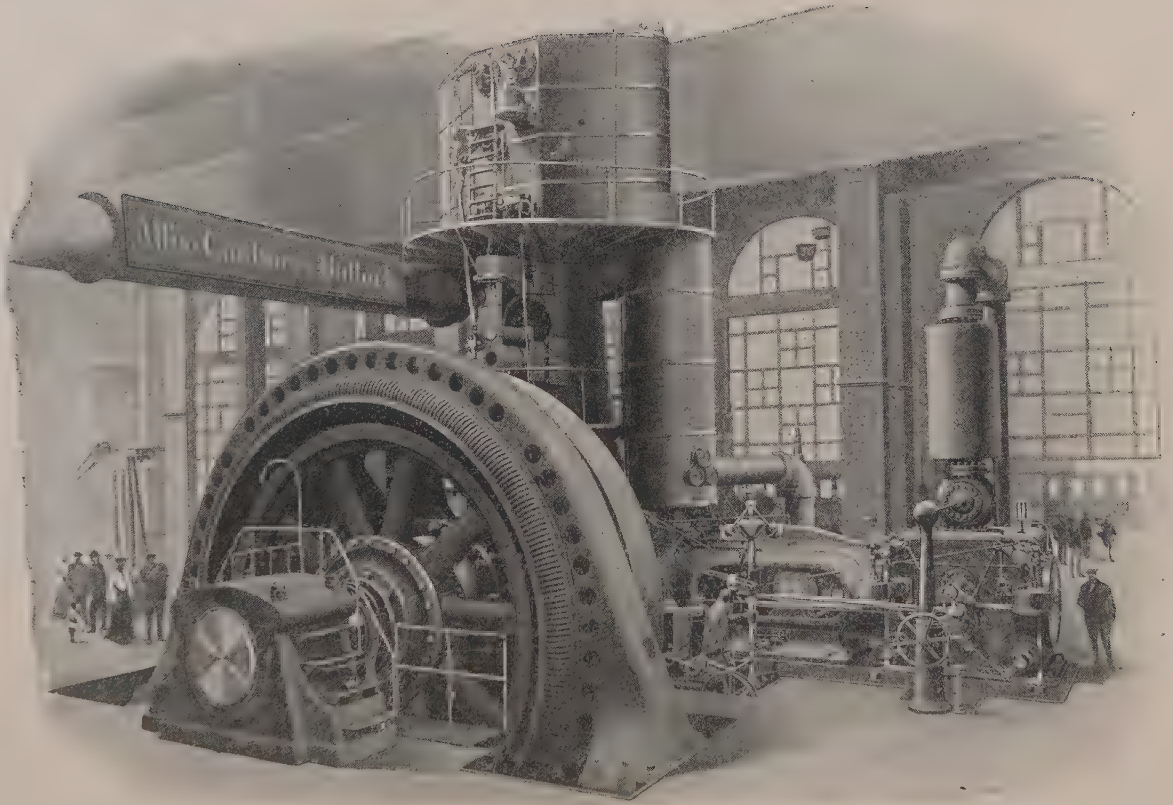
Allowing 12% of the applied E. M. F. to be lost in the armature and field winding the voltage to be generated is

$$220 \times .88 = 193 \text{ volts (approx.).}$$

The current capacity is to be

$$\frac{8{,}500}{193} = 44 \text{ amperes (approx.).}$$

Hence the armature is to be designed to generate a total E. M. F. of 193 volts at a speed of 900 revolutions per minute, the current capacity to be 44 amperes.



5,000 H. P. ALLIS-CHALMERS ENGINE. DIRECT-CONNECTED TO GENERATOR.

Carries 5,600 H. P, with 15 inches vacuum.

Machinery Hall, World's Fair, St. Louis.

MANAGEMENT OF DYNAMO-ELECTRIC MACHINERY.

The object of this instruction paper is to set forth the most important features which must be considered in the actual handling and operation of electric generators and motors. The principles and general construction of direct-current (D. C.) and alternating-current (A. C.) generators and motors, are treated elsewhere.

The subject may be divided into three parts as follows:

A. The Selection, Erection, Connection, and Operation.
B. The Inspection and Testing.
C. The Troubles or ''Diseases'' and Remedies.

SELECTION OF A MACHINE.

The voltage, capacity, and type of machine are dependent upon the system to which it is to be connected, and the purpose for which it is to be utilized, but there are certain general features which should be considered in every case.

Construction. This should be of the most solid character and guaranteed first-class in every respect, including materials and workmanship.

Finish. A good finish is desirable, since it is likely to cause the attendant to take greater care of the equipment.

Simplicity. The machine should be as simple as possible in all its parts; peculiar or complicated features should be avoided, unless absolutely essential for the operation of the system.

Attention. The amount of attention required by the machine should be small. The number of screws or nuts should be reduced to a minimum, and they ought always to be provided with some locking device to prevent them from becoming loose. The brushes should be capable of being easily adjusted and self-feeding, so that they may "follow" or make up for any trifling eccentricity of the commutator. The bearings should be self-oiling, and in the smaller sizes self-aligning.

Handling. An eye-bolt or other means by which the machine can be easily lifted and moved is desirable. It ought to be possible to take out the armature conveniently by removing one of the bearings, or the tops of the field magnet, frame and bearings, or by moving the halves sideways if the frame is split vertically. The armature and field windings should be so designed and mounted that their removal for repairs is an easy matter.

Interchangeability. The machine selected should preferably be one of a regular and standard type, so that extra parts can be obtained without needless delay.

Regulation. Some form of regulating device should be provided by means of which the E. M. F. or current of a generator, or the speed, and in some cases the direction of rotation of a motor, can be readily and accurately controlled.

Form. The machine should be symmetrical, well-proportioned, compact and solid in form. The large and heavy portions should be placed as low as possible, to give greater stability.

Weight. It is a mistake to select a very light machine when it is for stationary use, since weight increases its strength, stability, and durability.

Capacity. This should be ample for the work to be done; in fact it is advisable to allow a margin for increase. The machine should be provided with the maker's name-plate, specifying the rated current, voltage, speed and capacity. The manufacturer should also guarantee the following: That the machine does not heat up in any part of its windings, to more than 50° C, after a run of six hours' duration, under rated load conditions;* also that it is able to carry a 25 per cent overload for two hours, and momentary overloads of 50 per cent, without excessive heating or sparking.

Cost. It is usually an error to select a generator or motor simply because it is cheap, since both the materials and workmanship required for the construction of a high-grade electrical machine are costly.

MECHANICAL CONDITIONS.

Location. The place chosen for the machine should be *dry, free from dust or grit, light, and well ventilated.* It must also be arranged so that there is room enough for the removal of the armature without shifting or turning the machine.

Foundations. It is of great importance to have the machine firmly placed upon a good and solid foundation; otherwise, no matter how well constructed and managed, the vibrations occurring on a poor foundation will produce sparking at the brushes, and its accompanying troubles.

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*Note. By resistance measurements.

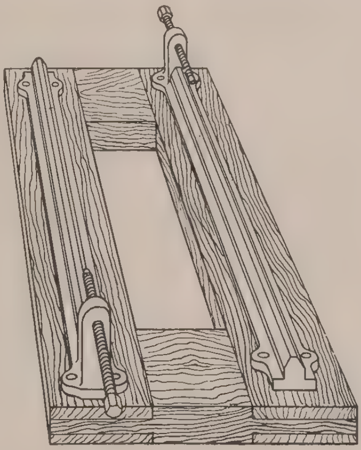

Fig. 1.

It is also necessary, if the machine is belt-driven, to mount it upon rails or a sliding bed-plate provided with holding-down bolts and tightening screws for aligning and adjusting the belt while the machine is in operation. (See Fig. 1). The machinery foundations consist of a mass of stone, masonry, brickwork, or concrete, upon which the machinery is placed and usually held firmly in place by bolts passing entirely through the mass. These bolts are built into the foundations, the proper position for them being determined by a wooden template suspended above the foundation, as shown in Fig, 2. The bolts are preferably surrounded by iron pipe that fixes them longitudinally but allows a little side play which may be necessary to enable them to enter the bed-plate

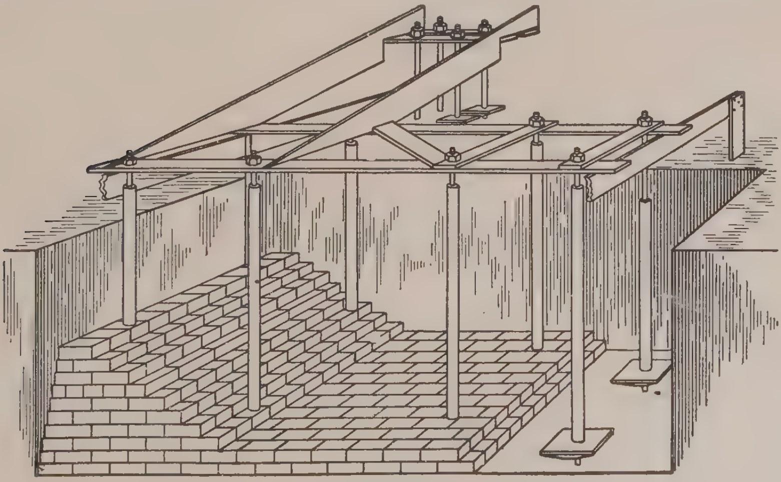

Fig. 2.

holes readily. The brickwork for machinery foundations should consist of hard burned bricks of first quality, *laid in good cement mortar.* Ordinary *lime mortar is entirely unfit* for the purpose, being likely to crumble away under the effect of the vibrations caused by the machinery. Brick or concrete foundations should be finished with a cap of bluestone or cement. This tends to hold the foundation together, and forms a level surface upon which to set the machinery. If the engine and generator are provided with a cast-iron sub-base, the capping may be dispensed with

Fixing the Machine. In fixing either direct-connected or belt-driven machines, first determine, with a long straight edge and spirit level, if the top of the foundation is level and true. If this is found to be the case, the holding-down bolts may be dropped into the holes in the foundation, if they are not already built in, and the machine carefully placed thereon, the ends of the bolts being passed through the holes in the bed-plate and secured by a few turns of the nuts. The machine should then, if belt-connected, be carefully aligned with the transmitting pulley or fly wheel. Particular attention should be paid to the alignment of the pulleys in order that the belt may run properly. If direct-connected, the dynamo bed-plate and armature shaft must be carefully aligned and adjusted with respect to the engine shaft, raising or lowering the bed-plates of the corresponding machines by means of thin cast-iron or other wedges; and the generator frame should also be adjusted to its proper height by means of thin strips of metal or fiber set between its supporting feet and the bed-plate. Having thus aligned and leveled the machine, it should next be grouted with thin cement. This is done by arranging a wall of mud or wooden battens around the bed-plates of the machines, and running in thin cement until the holding-down bolt holes are filled, and the cement has risen to the level of the under side of the bed-plate. When the cement has set, the wall may be removed and the nuts on the holding-down bolts drawn up. This firmly fixes the machine upon its foundation.

Mechanical Connections. Various means are employed to connect the engine or other prime mover with the generator, or the motor with the apparatus to be driven. The most important are as follows:

Direct Connection.
Belting.
Rope Driving.
Toothed Gearing.

Other apparatus, such as shafting, clutches, hangers and pulleys, are used in connection with the above means.

Direct Connection. This is the simplest, and for that reason the most desirable, means of connection, provided it can be carried out without involving sacrifices that offset its advantages. This method, also called direct coupling or direct driving, compels the engine and generator to run at the same speed, which gives rise to some difficulty, as the most desirable speeds of the two machines do not usually agree. The natural speed of a generator is high, while that of an engine is low; hence to obtain the same voltage from a direct-connected generator, more inductors are necessary, or the flux cut must be increased. Accordingly, the armature and frame of the direct-connected generator must be larger, thus making it a more expensive machine than the belt-driven.

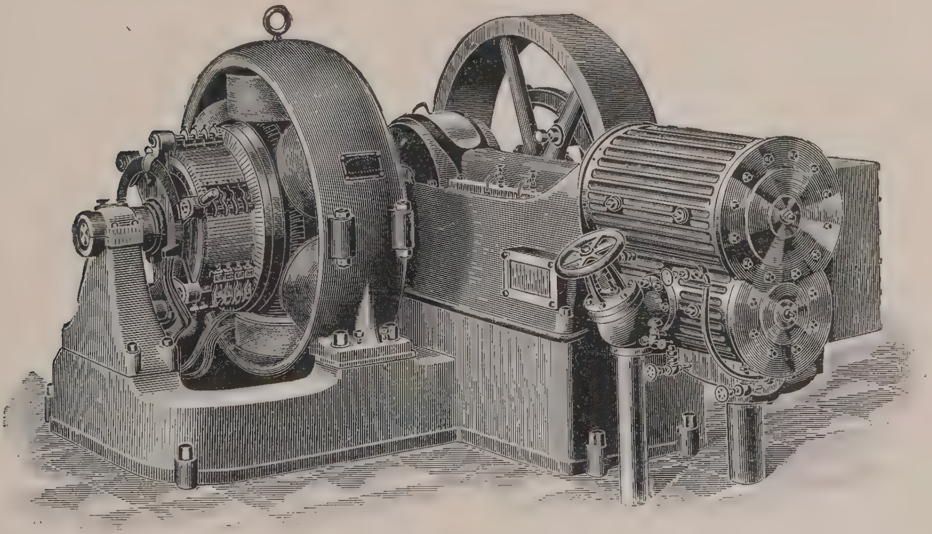

Fig. 3.

The direct connection of an engine and generator is accomplished in several ways; the simplest of which consists in mounting the armature of the generator directly on one end of the shaft of the engine. This may be accomplished in any one of several ways. Fig. 3 represents the three-bearing method. Two-and-four-bearing methods are also used. These secures the great advantages: that accurate alignment is readily obtained, and space occupied reduced to a minimum, and the mounting of the bearings on a common sub-base avoids trouble due to unequal settling.

Another form of direct coupling is that in which an engine and a generator, each complete in itself, and each having two bearings, are coupled together by some mechanical device, which may be either rigid or slightly elastic or adjustable. In the former case the two shafts are practically equivalent to a single one, which, while making it easy to remove either machine for repairs, is somewhat objectionable owing to the fact that it requires larger foundations, and introduces the difficulty of accurately aligning four bearings. The use of a flexible coupling avoids the necessity of perfect alignment, and also the serious trouble that might arise if the settling or the wear of the bearings should be uneven. There are various forms of flexible coupling. One of the forms manufactured by the Westinghouse Machine Company is shown in Fig. 4, the flexibility being provided by the springs which hold the two parts of the coupling together.

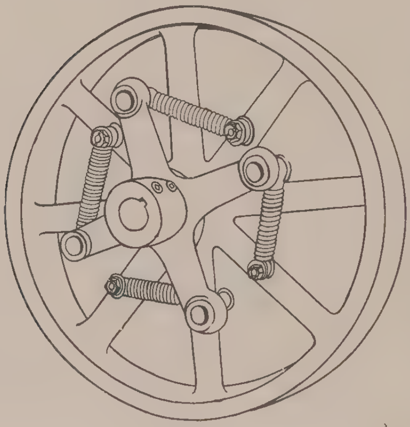

Fig. 4.

The direct coupling of generators with turbines can be carried out without departing from the natural speed of either machine, since the ordinary speed of a turbine agrees closely with the normal speed of a generator of the corresponding capacity.

The relative efficiency of direct coupling and belting depends greatly upon the conditions; but in general the former is more efficient at or near rated load, and the latter at light loads. *The simplicity, compactness, and positive and noiseless action of direct connection* have caused it to become the most approved method.

Belting. If the generator or motor is not directly connected, one to the prime mover and the other to the apparatus to be driven, they are usually connected by some form of belting. The kind of belting selected depends greatly upon conditions of drive, distances, etc.; and it may be leather, rawhide, rubber, or rope. For ordinary short drives, leather is the most desirable, though, when the power to be transmitted is small, rawhide belts are also satisfactory, especially as the cost is less than for leather belts. For considerable distances, rope driving answers very well because it is so much lighter and cheaper than an equivalent leather belt, though grooved pulleys are required, making the total cost about the same. Rubber belts are used to advantage in driving generators from water turbines, where the belt might be exposed to moisture. Leather belting is usually the most reliable and satisfactory for general application, except for very short drives, where a form of chain belt works best. There are three thicknesses of leather belting—single, light-double, and double. For use in connection with generators, motors, or other high-speed machinery, the "light-double" belting is usually the best.

The exact amount of power that a given belt is capable of transmitting is not very definite. The ordinary rule is that "single" belt will transmit 1 horse-power for each inch of its width when traveling at a speed of 1,000 feet per minute. If the speed is greater or less, the power is proportionately increased or decreased. The statement of H. P. transmitted is based upon the condition that the belt is in contact with the transmitting pulley around one-half of its circumference, or 180°, which is usually the case. If the arc of contact is less than 180°, the power transmitted is less in the following proportion: An arc of 135° gives 84 per cent, while 90° contact gives only 64 per cent of the power derived from a belt contact of 180°. If on the other hand, the upper side sags downward, which is always desirable, the belt is in contact with more than half the circumference of the pulley; and thus the grip is considerably increased and more power can be transmitted. These facts make it very desirable to have the *loose side of the belt on top*. If the loose side is below, it sags away from the pulley and is also likely to strike the floor.

The complete expression for determining the width of a single belt required to transmit a given horse-power is as follows:

$$W = \frac{H. P. \times 1,000}{S \times C},$$

where W is the width of the belt in inches; H. P. the horse-power to be transmitted; S the speed of the belt in feet per minute, which is equal to the circumference of the driving pulley in feet multiplied by the number of revolutions per minute;* and C a factor dependent upon the arc of contact.

"Double" belting is expected to transmit one and one-half ($1\frac{1}{2}$), and "light-double" one and one-quarter ($1\frac{1}{4}$) times as much power as "single" belting of the same width. Belting formulas are only approximate, and should not be applied too rigidly, since the grip of the belt upon the pulley varies considerably under different conditions of tension, temperature and moisture. The smooth side of a belt should always be run against the pulley, as it transmits more power and is more durable. Belting used for electric machinery, being usually high-speed, should be made "endless" for permanent work, as this makes less noise; but it may be used with laced joints, temporarily. A spliced or "endless" joint is made as follows:—Both ends of the belt are pared down on one side (opposite) with a sharp knife, into the form of a long thin wedge, so that when laid together a long uniform joint is obtained of the *same thickness as the belt itself*. The parts are then firmly joined with cement and sometimes with rivets also. It may be necessary to splice or lace a belt while in position on the pulleys; and for this purpose some form of belt clamp (Fig. 5) should be employed.

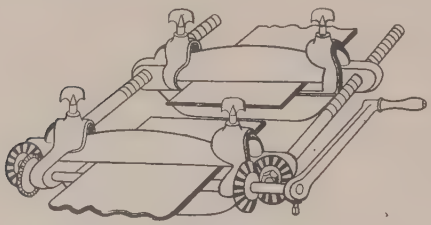

Fig. 5.

If a belt is ordered endless, or is spliced away from the pulleys, great care should be exercised in determining the exact length required. A string that will not stretch, or preferably a wire put around the pulleys in the position to be occupied by the belt, is the best way to avoid a mistake. In measuring for a belt, the generator or motor should be moved on its sliding base so as to make the distance between shaft centers a minimum, in order to allow for the stretch of the belt, which may be as much as ½ inch per foot of length.

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*Note. Belts slip or "creep" on the pulley about 2 per cent; hence, in determining the size of pulleys whose speed must be accurate, the calculated belt speed should be about 2 per cent too high.

The lacing of a belt is a very simple and common method of making a joint; but should not be permanently employed at high speeds for electric machinery belting, as it is liable to pound on the pulleys, producing noise, vibration and sparking; and in the case of generators it is also likely to cause flickering in the lamps. In lacing belts, the ends should be cut *perfectly square, and there should be as many stitches of the lace slanting to the left as there are to the right;* otherwise the ends of the belt will shift sidewise owing to the unequal strain, and the projecting corners may strike or catch in the clothing of persons. A good way to accomplish this is shown in Fig. 6. The various holes should be made with a circular punch, the nearest one being about ¾ inch from the side, and the line through the center of the row of holes about 1 inch from the end of the belt. In large belts these distances should be a little greater. A regular belt lacing of strong pliable leather or a special wire is used. The lacing is doubled to find its middle; and the two ends are passed through the two holes marked "*1*" and "*1a*," precisely as in lacing a shoe. The two ends are then passed successively through the two series of holes, in the order in which they are numbered, *2*, *3*, *4*, etc., and *2a*, *3a*, *4a*, etc., finishing at *13* and *13a*, which are additional holes for securing the ends of the lace. The great advantage of this method of lacing is that the lace lies on the pulley side perfectly parallel to the direction of motion.

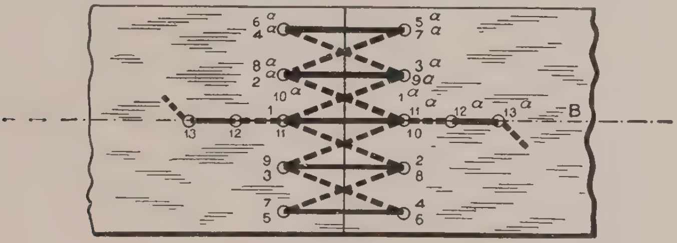


Fig. 6.

Perforated belts are often employed for the reason that a film of air is likely to be imprisoned between the belt and the pulley, thus preventing a good grip. Hence small perforations are sometimes made in the belt, especially for high-speed operation (3,000-5,000 feet per minute), to allow the air to escape; and since these are in the form of narrow slits, with their greatest dimension in the direction of motion, they do not materially reduce the strength of the belt.

Arrangement and Care of Belting. It is very desirable, for satisfactory running, that belts should be reasonably long and nearly horizontal. The distance between the centers of two belt-connected pulleys should be not less than 3 times the diameter of the larger pulley. The belt should be just tight enough to avoid slipping, without straining the shaft or bearings. The two shafts which are to be belt-connected must be perfectly parallel, and the centers of the face of the driving and driven pulleys must be exactly opposite to each other, in a straight line perpendicular to the axis of the shafts. The machines should then be turned over slowly with the belt on, to see if the latter tends to run to one side of the pulley, which would show that it is not yet properly "lined up," in which case one or both machines should be slightly shifted, until the belt runs properly. If possible, the machine and belt should be set and adjusted so as to cause the armature to move back and forth in the bearings while running, on account of the side motion of the belt, and thus make the commutator wear more smoothly, and distribute the oil in the bearings.

It is always desirable to have belts as pliable as possible; hence the occasional use of a good belt dressing—as neatsfoot oil, etc.—is recommended. Rosin and other sticky substances are sometimes applied to increase the adhesion; but this is a practice allowable only in an emergency, as it may destroy the belt surface.

In places where the belting is very much exposed, and liable to catch in the clothing of any person, it is advisable to surround it by a railing or box.

Rope Driving possesses advantages over ordinary belting in some cases. The rope runs in V-shaped grooves in the peripheries of the pulleys, and thereby obtains a great grip by a sort of wedging action. The kinds of rope ordinarily employed for this purpose are cotton, hemp, rawhide and wire. The general advantages are:

1. Economy in cost.

2. Large amount of power that can be transmitted with a given diameter and width of pulley, on account of the grip obtained.

3. It is almost noiseless.

4. Ropes, on account of their lightness, can be used to transmit power over greater distances than are possible with any other form of belting; and also for very short distances on account of the wedging action. Manila rope is generally used in the United States, being of three strands, hawser laid, and may be from $\frac{1}{2}$ inch to 2 inches in diameter. The breaking strength varies from 7,000 to 12,000 pounds per square inch of cross-section. It has been found that the best results are obtained when the tension in the driving side of the rope is only 3 to 4 per cent of the breaking strength.

The diameter of a single rope necessary to transmit a required H. P. is given by the formula:

$$D^2 = \frac{825 \text{ H.P.}}{V\left(200 - \frac{V^2}{1,072}\right)},$$

in which H. P. = horse-power transmitted;
V = velocity of rope in feet per second;
D = diameter of rope in inches.

The maximum power is obtained at a speed of about 84 feet per second. With higher speeds the centrifugal force becomes so great that the power transmitted decreases rapidly, and at about 142 feet per second it counteracts the whole allowable tension (200 D^2 pounds) and no power is transmitted.

Arrangement of Rope Belting. There are two methods of arranging rope transmission: one consists in using several separate belts; and the other employs a single endless rope which passes spirally around the pulley several times and is brought back to the first groove by a slanting idle pulley, and therefore is called the "wound" system. The separate ropes do not require the carrying-over pulley, and if one rope breaks, those remaining are sufficient to transmit the power temporarily; whereas an accident with the single-rope system entirely interrupts the service. In the "multi-rope" system it is practically impossible to make and maintain the belts of exactly equal length, hence the tensions on the various ropes differ, and they hang at different heights on the slack side, producing an awkward appearance.

Toothed Gearing possesses the decided advantages of positive action and the ability to give large ratios of speed and small side pressure on the bearings. Nevertheless it is seldom employed for driving generators. As the most extensive applications of gearing for electrical purposes are in connection with railway motors, it will be taken up under that heading.

SHAFTING.

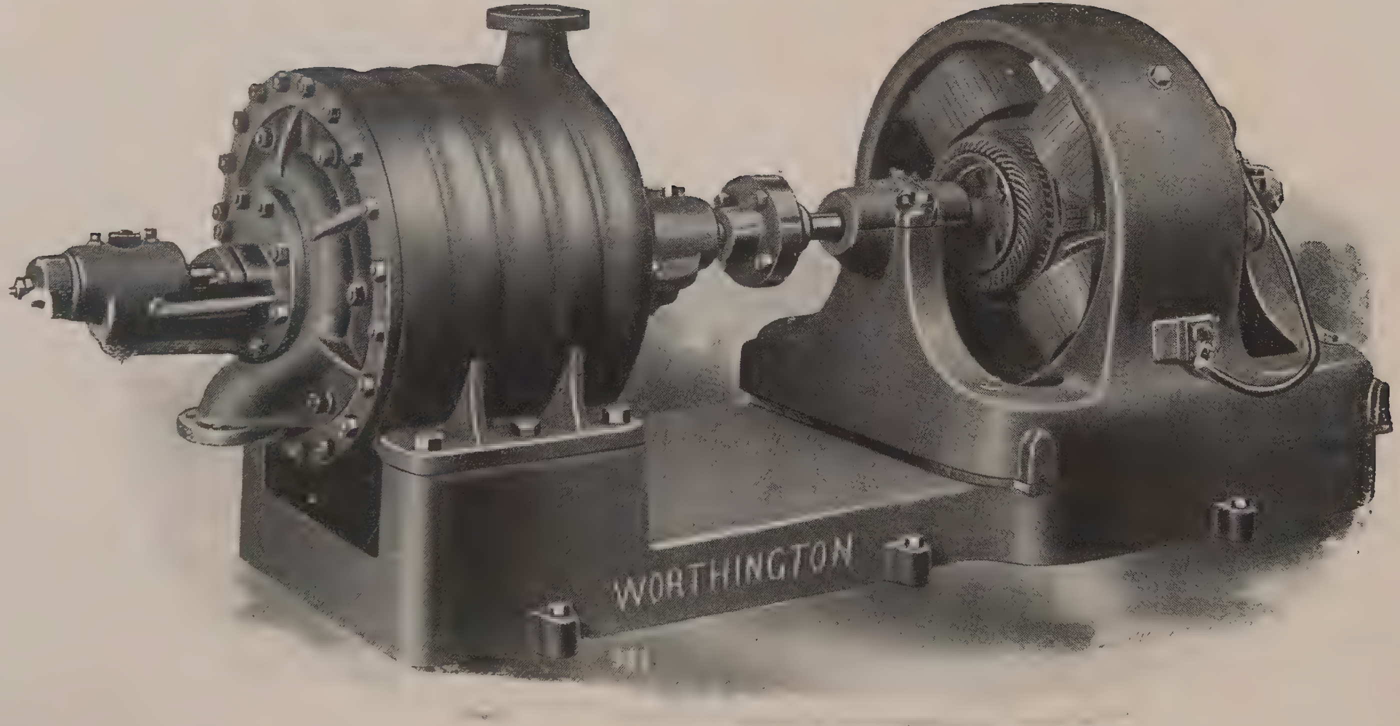
An intermediate or counter shaft is not desirable since it increases the complication and frictional losses of the system; but it is often necessary in the generation or application of electric power, either to obtain a greater multiplication of speed than is possible by belting directly, or to enable a single engine or motor to drive a greater number of machines.

The two important kinds of shaftings are "cold-rolled" and "turned." The former is rolled to the exact size and requires no further treatment. It has the advantage of a smooth, hard surface, but it is difficult to make perfectly true and straight. Turned-steel shafting is most commonly employed, and has the advantage that shoulders, journals, or other variations in size can be easily made on it. The following table gives the ordinary data for shafting:

TABLE I.

Shafting.

Diameter in inches.	Weight lbs. per ft.	Allowable H. P. transmitted at 100 r. p. m.	Width of key seat in inches.
$1\frac{7}{16}$	5.5	4.3	$\frac{3}{8}$
$1\frac{15}{16}$	10.	10.	$\frac{1}{2}$
$2\frac{7}{16}$	15.8	20.	$\frac{3}{4}$
$2\frac{15}{16}$	23.	34.	$\frac{3}{4}$
$3\frac{7}{16}$	31.5	54.	$\frac{7}{8}$
$3\frac{15}{16}$	41.	80.	1
$4\frac{7}{8}$	62.8	156.	1
$5\frac{7}{8}$	91.1	270.	1



FIVE-STAGE MOTOR-DRIVEN TURBINE PUMP.

Adapted to Heads up to 750 Feet.

With speeds greater than 100 r. p. m., the allowable H. P. varies directly in proportion to the speed employed.

ASSEMBLING OF THE MACHINE.

In unpacking and putting the machine together, great care should be used to avoid the least injury to any part, to clean scrupulously each part, and to put the parts together in exactly the right way. This care is particularly important with regard to the shaft, bearings, magnetic joints, and electrical connections, from which every particle of grit, dust, metal chips, waste, etc., should be removed. It is advisable to study carefully the blue prints or instruction matter usually sent with each machine, before attempting to put it together. The armature must be handled with great care in order not to injure the wires and their insulation as well as the commutator and shaft. The armature should be handled as far as possible by the shaft, and when it must be placed on the ground a pad of cloth or layer of boards should be interposed. A convenient form of sling for handling armatures with their shafts in position is shown in Fig. 7. The bearings should be carefully cleaned, set in exactly the right positions, and firmly secured. The tops should be left loose for a short time, so that the tendency to heat up at the first run may be decreased; and after that they

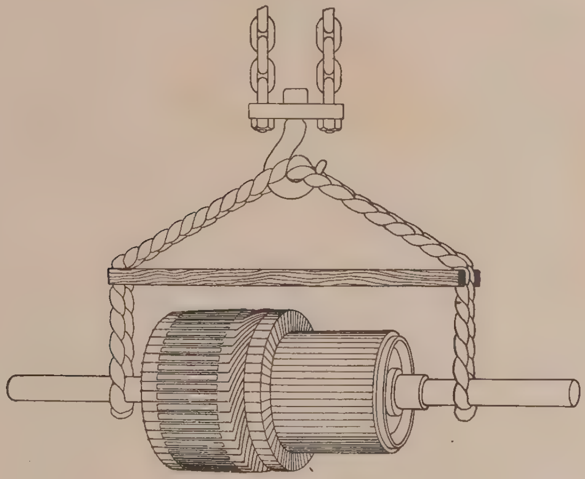


Fig. 7.

should be drawn up tight. The field frame should be set so that the air gap is the same for all pole pieces, as otherwise the machine will be magnetically unbalanced and tend to spark badly.

The adjustment of the brushes, etc., should preferably be left until the machine is electrically connected and ready to receive its trial run.

METHODS OF WIRING.

Before laying the wires, the circuits should be carefully mapped out and the work so planned as to secure the simplest arrangement. The wiring should then be installed neatly and in accordance with the rules of the National Board of Fire Underwriters and of the local department having supervision. Otherwise unnecessary trouble, delay and expense may be incurred.

The wire may be installed in one of two general methods, *viz.:*

Exposed on	Cleats.
	Knobs.
	Bushings.
Concealed in	Wooden moulding.
	Iron conduit.
	Terra cotta conduit.

The wire should preferably be either rubber-covered or made up in the form of lead cables. Exposed wires possess the advantages of cheapness, as well as accessibility for inspection and repair; and any short circuit or ground is readily seen and removed, whereas it might cause great uncertainty and delay when the wires are concealed.

Concealed conductors, especially where they are placed under the floor, have the great advantage over exposed wiring, in that they are entirely out of the way. This is especially important in large installations, where overhead traveling cranes are almost a necessity.

When alternating-current conductors are enclosed in iron conduits, both wires of each phase, or all the wires, must be run in the same duct, otherwise the inductance would be excessive.

All conductors, including those connecting the machine with the switchboard, as well as the bus bars on the latter, should be of ample size to be free from overheating and excessive loss of voltage. The drop between the generator and switchboard should not exceed $\frac{1}{2}$ per cent at full load, because it interferes with proper regulation and adds to the less easily avoided drop on the distribution system.

The safe carrying capacities of copper conductors as recommended by the Board of Fire Underwriters, are given in the following table:

TABLE II.

Safe Carrying Capacities of Copper Wires.

B. & S. G.	Rubber Insulation. Amperes.	Other Insulations. Amperes.	Circular Mils.
18	3	5	1,624
16	6	8	2,583
14	12	16	4,107
12	17	23	6,530
10	24	32	10,380
8	33	46	16,510
6	46	65	26,250
5	54	77	33,100
4	65	92	41,740
3	76	110	52,630
2	90	131	66,370
1	107	156	83,690
0	127	185	105,500
00	150	220	133,100
000	177	262	167,800
0000	210	312	211,600
Circular Mils.			
200,000	200	300	
300,000	270	400	
400,000	330	500	
500,000	390	590	
600,000	450	680	
700,000	500	760	
800,000	550	840	
900,000	600	920	
1,000,000	650	1,000	
1,100,000	690	1,080	
1,200,000	730	1,150	
1,300,000	770	1,220	
1,400,000	810	1,290	
1,500,000	850	1,360	
1,600,000	890	1,430	
1,700,000	930	1,490	
1,800,000	970	1,550	
1,900,000	1,010	1,610	
2,000,000	1,050	1,670	

The lower limit is specified for rubber-covered wires to prevent gradual deterioration of the high insulations by the heat of the wires, but not from fear of igniting the insulation. The question of drop is not taken into consideration in the above tables.

The carrying capacity of Nos. 16 and 18, B & S. gage wire is given, but no smaller than No. 14 is to be used

The safe carrying capacity of insulated aluminum wire is 84 per cent of that given for copper wires of corresponding size and insulation.

Switches are devices for closing and opening the various circuits or branches of an electrical distribution system. A knife switch should always be employed when the capacity of the circuit to be controlled exceeds 10 amperes. It may be single-, double-, or triple-pole; single- or double-throw; and with or without fuses as desired. If the rated capacity of a switch exceeds 25 amperes, its terminals must be provided with lugs into which the ends of the conducting wires should be soldered. The principal parts of a knife switch (Fig. 8) are the *base* (*a*), which must consist of a non-combustible, non-absorptive insulating material; the *hinges* (*b*), which carry the *blades* (*c*); the contact *jaws* or *clips* (*d*); the insulating *cross-bar* (*e*); and the *handle* (*f*). The hinges, blades and jaws should be made of pure copper, of sufficient cross-section to insure mechanical stiffness and proper carrying capacity, and their contact surfaces must not be less than 1 square inch per 75 amperes of the rating. The hinges and contact jaws must be springy enough to insure good contact with the blades. The blades and jaws must be so shaped that they open along their entire length simultaneously; otherwise the arc which is formed upon opening a loaded circuit will burn off the last points of contact. In fact this arc, when produced by a heavy current, is very difficult to control; and switches should never be opened on heavily-loaded circuits except in an emergency. In practice, however, some form of electro-magnetic circuit-breaker is employed for the purpose, and may be operated automatically with overload, or by hand at any time.

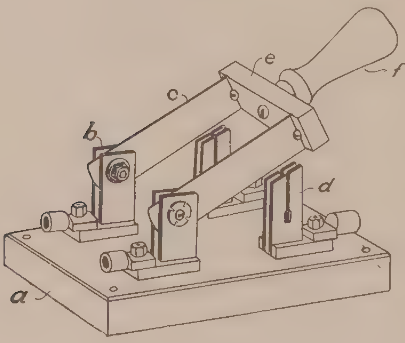


Fig. 8.

Knife switches should be so placed that *gravity tends to open* rather than to close them. They should always be located in dry, accessible places and grouped as far as possible If located in exposed positions they should be enclosed in slate or equivalently lined cabinets. The distances between the parts of opposite polarity, in an approved knife switch, must never be less than the values given in the following table:

TABLE III.

Switch Data.

125 VOLTS OR LESS:	Minimum Separation of Nearest Metal Parts of Opposite Polarity.	Minimum Break-Distance.
For Switchboards and Panel Boards—		
10 amperes or less	$\frac{3}{4}$ inch	$\frac{1}{2}$ inch.
11 25 “	1 “	$\frac{3}{4}$ “
26-50 “	$1\frac{1}{4}$ “	1 “
For Individual Switches—		
10 amperes or less	1 inch	$\frac{3}{4}$ inch.
11- 35 “	$1\frac{1}{4}$ “	1 “
36- 100 “	$1\frac{1}{2}$ “	$1\frac{1}{4}$ “
101- 300 “	$2\frac{1}{4}$ “	2 “
301- 600 “	$2\frac{3}{4}$ “	$2\frac{1}{2}$ “
601-1,000 “	3 “	$2\frac{3}{4}$ “
126 TO 250 VOLTS:		
For all Switches—		
10 amperes or less	$1\frac{1}{2}$ inch	$1\frac{1}{4}$ inch.
11- 35 “	$1\frac{3}{4}$ “	$1\frac{1}{2}$ “
36- 100 “	$2\frac{1}{4}$ “	2 “
101- 300 “	$2\frac{1}{2}$ “	$2\frac{1}{4}$ “
301- 600 “	$2\frac{3}{4}$ “	$2\frac{1}{2}$ “
601 1,000 “	3 “	$2\frac{3}{4}$ “

On switchboards, the above spacings for 250 volts direct current are also approved for 440 volts alternating current. Switches on switchboards with these spacings intended for use on alternating-current systems with voltages above 250, must be stamped with the voltage for which they are designed, followed by the letters “A. C.”

251 TO 600 VOLTS:		
For all Switches—		
10 amperes or less	$3\frac{1}{2}$ inch	3 inch.
11 - 35 “	4 “	$3\frac{1}{2}$ “
36-100 “	$4\frac{1}{2}$ “	4 “

Auxiliary breaks or the equivalent are recommended for switches designed for over 300 volts and less than 100 amperes, and will be required on switches designed *for use in breaking currents* greater than 100 amperes at a pressure of more than 300 volts.

For three-wire systems switches, must have the break-distance required for circuits of the potential of the outside wires.

Safety Fuses and Cut-outs. Almost all electrical circuits, except those for constant-current arc lighting, are protected from abnormal increase of current by safety fuses. These consist of wires or strips of metal introduced into the circuit, and so designed in cross-section and resistance that they will melt and open the circuit in case of excessive current, before the rest of the system becomes unduly heated.

The requirements for effective safety fuses may be stated as follows:

1. They should melt at a definite current.
2. They should not change in this respect by the effect of time, nor by heating or other action of the current, nor, in fact, under any reasonable conditions.
3. They should act promptly.
4. They should give firm and lasting contacts with the terminals to which they are attached.

These fuses are of two general types:

(*a*) Open or link fuses.
(*b*) Enclosed or cartridge fuses.

The open or link fuses (Fig. 9) consist of strips of fusible alloy provided with copper terminals. Each size is designed to carry a certain normal current, but will melt and open the circuit when the current exceeds that rating by 25 per cent. When a link fuse "blows" as a result of overloading, the rupture is accompanied by a flash, and by spattering of the fused material. With large currents this phenomenon is a source of danger, and the use of enclosed fuses is accordingly recommended whenever the rating of the fuse exceeds 25 amperes.

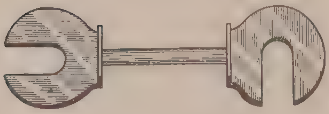


Fig. 9.

Fig. 10.

Enclosed fuses (Fig. 10) have a casing around the fusible material, which prevents the dangerous spattering and which also smothers the arc that tends to form whenever a fuse blows.

Fuses should always be employed when the size of the wire changes, or where connections between any electrical apparatus and the conductors are made. They must be mounted on slate, marble, or porcelain bases; and all metallic fittings employed in making electrical contacts must have sufficient cross-section to insure mechanical stiffness and carrying capacity.

Electro-magnetic Circuit-Breakers or **Limit Switches** are frequently used in place of fuses to protect electrical circuits. Their general construction and application are indicated in Fig. 11. The current is led through a helix A the electro-magnetic action of which, when the current reaches a predetermined limit, automatically releases the blades from contact with the jaws and thus opens the circuit. The final break occurs at carbon tips, thus preventing destructive arcing at the copper contacts. Circuit-breakers possess the following advantages over fuses:

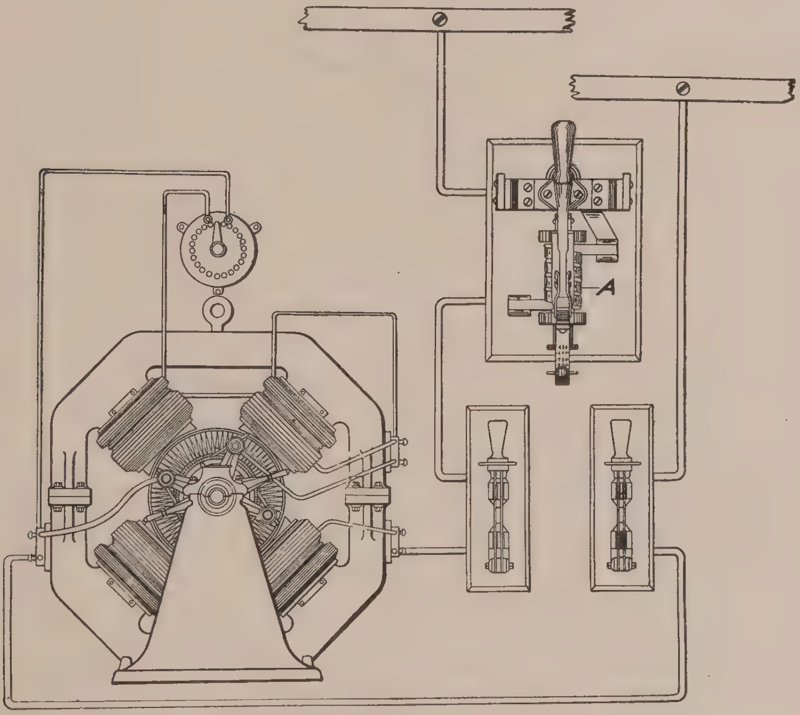


Fig. 11.

1. They can be employed as switches if desired.
2. They can easily be reset and thus put into condition for acting again.

3. Their range can be easily varied within considerable limits.
4. They can also be made to operate "tell tales" whenever the circuit they control is opened.

On account of these general advantages, their use is advisable on switchboards of systems that are liable to frequent overloads. The circuits, however, should, as a rule, be provided also with fuses, since it is possible that the circuit-breaker may fail to open, owing to corrosion or other cause.

Starting-Boxes should always be furnished with D. C. motors, for the following reason: If the line voltage should be applied directly to the terminals of the armature while it is standing still, a very excessive current would flow, since the resistance is low and no C. E. M. F. exists. Hence, to prevent injury to the winding, a resistance is inserted between one supply terminal and the armature in order to reduce the electromotive force at the motor terminals while it is speeding up, the resistance being gradually reduced until completely removed when rated speed is reached. All motor starting-boxes must also be provided with a **no-voltage release.** This consists of an electro-magnet in series with the shunt-field circuit, which holds the rheostat arm in the operating position as long as current flows through the shunt field from the line. If the line switch be opened or the shunt-field circuit accidentally broken, the device becomes demagnetized and releases the arm, which returns to its starting position (all resistance in circuit) by the action of a spring or of gravity. The starting-boxes of larger motors are also frequently equipped with **overload releases.** These, practically, are electro-magnetic circuit-breakers which open the supply lines if the motor becomes greatly overloaded. The general arrangement of switches, cut-outs and starting-boxes should be in accordance with the following extract from the Rules of the National Board of Fire Underwriters:

"Each motor and starting-box must be protected by a cut-out and controlled by a switch, said switch plainly indicating whether 'on' or 'off.' The switch and rheostat must be located within sight of the motor, except in cases where special permission to locate them elsewhere is given, in writing, by the Inspection Department having jurisdiction.

"Where the circuit-breaking device on the motor-starting rheostat disconnects all wires of the circuit, this switch may be omitted.

"Overload-release devices on motor-starting rheostats will not be considered to take the place of the cut-out required if they are inoperative during the starting of the motor.

"The switch is necessary for entirely disconnecting the motor when not in use; and the cut-out, to protect the motor from excessive currents due to accidents or careless handling when starting. An automatic circuit-breaker disconnecting all wires of the circuit, may, however, serve as both switch and cut-out."

The **Various Kinds of Circuit** on which motors and generators are commonly used, and the best type of machine in each case, are as follows:

TABLE IV.

Types of Machine for Various Kinds of Circuits.

DIRECT-CURRENT, CONSTANT-POTENTIAL.

Circuits on which potential or voltage is kept constant; machines, lamps, etc., being run in parallel.

Currents intended for—	Potential.	Generator should be—	Motor should be—
Electro-metallurgy.	1 to 150 volts	Shunt-wound.	Not used.
Incandescent lighting.	110 to 125 volts (2-wire sys.) 220 to 250 volts (2-or 3-wire sys.)	Shunt- or compound-wound.	Shunt-wound for constant speed. Sometimes series- or compound-wound for variable speed.
Electric railway Electric power.	500 to 660 volts	Compound-wound.	Series-wound for railway. Shunt-wound for stationary.

DIRECT, CONSTANT-CURRENT.

Circuits on which current or amperes are kept constant; machines, lamps, etc., being run in series.

Circuits intended for—	Current in Amperes.	Generator should be—	Motor.
Arc lighting.	6.8 or 9.6	Series-wound with current regulator.	No longer used.

ALTERNATING-CURRENT, POLYPHASE.

Constant-potential, two- or three-phase currents.

Circuits intended for—	Potential in Volts.		Generator should be—	Motor is—
Power transmission.	On the line, 5,000 to 60,000.	In the machines, varying 500 to 12,000	Separately excited.	Synchronous or Induction.

ALTERNATING-CURRENT, SINGLE-PHASE.

Almost always constant-potential.

Circuits intended for—	Potential in Volts.		Generator should be—	Motor should be—
Incandescent lighting. Arc lighting. Sometimes constant-current. Electric power.	Primary, 1,000 or more,	Secondary, 104 or 208.	Separately excited. Also sometimes composite-wound.	Synchronous. Induction. Series. Repulsion.

Diagrams of Connections are given for each important case to show what is actually required. These merely represent the path of the currents in the simplest way, the important thing being to have these paths right, and to know which parts or wires are to be connected. The case of plants operating with only a single generator will be first considered, and then the parallel or series operation of several machines described.

Shunt Dynamo, Supplying Constant-Potential Circuit. A machine of the above type is represented in Fig. 12, with the necessary connections. The brushes are connected to the two conductors forming the main circuit; also to the field-magnet coils S*h* through a resistance-box R, to regulate the strength of current and therefore the magnetism in the field. A voltmeter is also connected to the two brushes or main conductors, to measure the voltage or electrical pressure between them. One of the main conductors is connected through an ammeter A, which measures the total current on the main circuit. The lamps L, or motors M, are connected in parallel between the main conductors or between branches from them. This represents the ordinary low-tension system for electric light and power distribution from isolated plants or central stations.

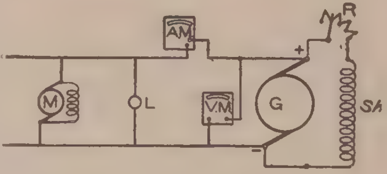


Fig. 12.

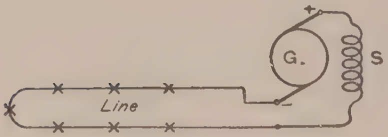


Fig. 13.

Series Dynamo Supplying Constant-Current Circuits. The connections in this case are extremely simple, the armature, field coils, ammeter, main circuit, and lamps all being connected in one series (Fig. 13), the current being kept constant. This system is used for series D. C. arc lighting.

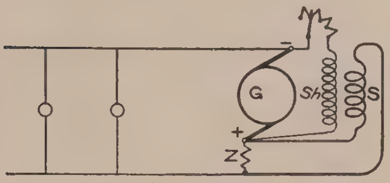


Fig. 14.

Compound Direct-Current Dynamo. This machine is a combination of the two foregoing types as regards field winding; but its load of lamps and motors are connected in parallel, as shown in Fig. 14. The resistance Z is known as the "series" shunt, and is for adjusting the percentage of compounding. The greater the resistance of Z, the greater the current passing through the series field, and the greater the compounding. This type of machine is most extensively employed in electric railway and in isolated plant work.

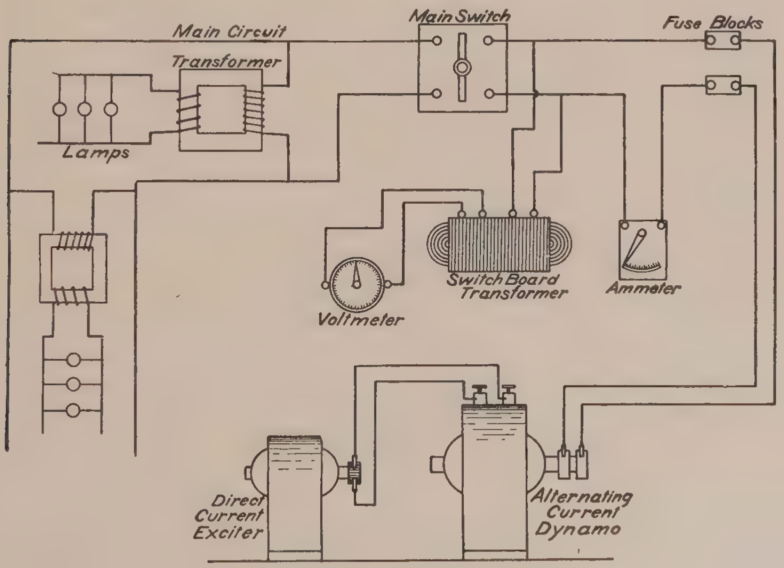


Fig. 15.

Alternating-Current Plants. The connections for a single-phase installation are shown in Fig. 15, in which the names of the different parts are given. This system is extensively used for lighting over considerable distances, and is very well adapted to street railway work. The wiring of a two-phase system is essentially double that given above, and can be treated as a system consisting of two single-phase circuits.

The wiring of a three-phase system is as shown in Figs. 16*a* and 16*b*, the former being known as the "Y" system or "Star" system, and the latter as the "Delta" (△) system or "Mesh" system. When the Y system is required for both lighting and power, it is arranged as shown in Fig. 16*c*.

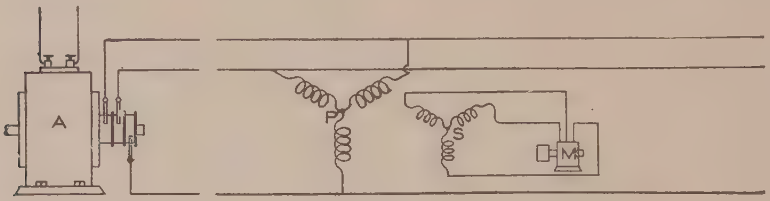


Fig. 16*a*.

The **Direction of Rotation** of the various machines is sometimes a matter of doubt or trouble. Almost any generator or motor is intended to be run in a certain direction; that is, it is called "right-handed" or "left-handed" according to whether the armature does or does not revolve like the hands of a clock, when looked at from the pulley end. Generators and motors are usually designed to be right-handed, but the manufacturer will make them left handed if specially ordered. This may be required because the other pulley to which the machine is to be connected happens to revolve left-handed; or it may be necessary in order to bring the loose side of the belt on top, or to permit the machine to occupy a certain position where space is limited.

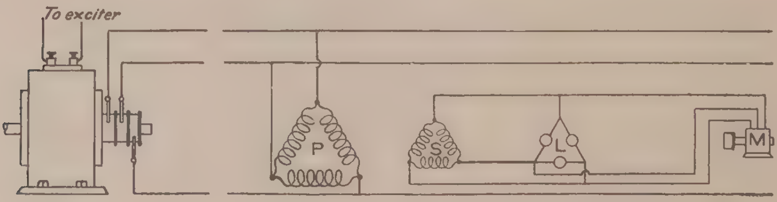


Fig. 16*b*.

To reverse the direction of rotation of an ordinary shunt (or series) direct-current bipolar motor, the brushes may simply be reversed as indicated in Fig. 17, without changing any connection. This changes the point of contact of each brush tip 180°.

If the machine is multipolar, a similar change must be made, amounting to 90° in a four-pole, 45° in an eight-pole machine, etc.

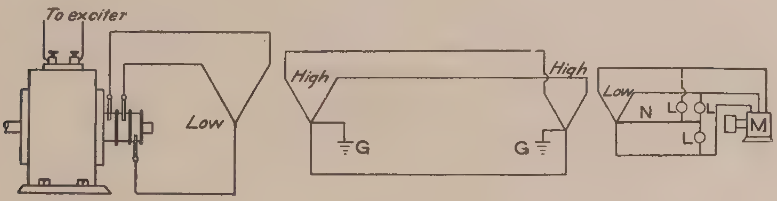


Fig. 16c

The direction of the current and the polarity of the field magnets remain the same as before; all that is changed is the direction of rotation and the position of the brushes. This applies to any machine (either motor or generator) except arc dynamos and one or two other peculiar machines, which require to be run in a certain direction to suit the regulating apparatus.

A separately excited alternating-current generator can be reversed in direction of rotation without changing any connection. A self-exciting or compound-wound alternator requires the brushes that supply the direct current to the field to be reversed upon the commutator, and their tips moved through an angle as above stated, if the rotation is to be reversed.

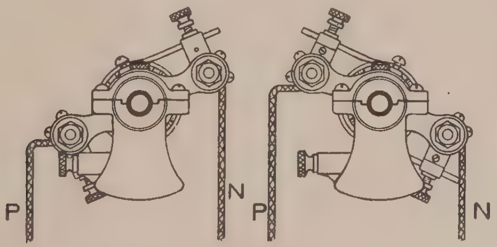


Fig. 17.

In any case, copper brushes (unless they be gauze brushes pressing radially upon the commutator) should point in the direction of rotation; but carbon brushes, particularly if they are perpendicular to the surface of the commutator, allow the armature to be revolved in either direction.

If the direction of the current from a generator is opposite to that desired, the two wires leading from it should exchange places in the terminals. If this is not desirable, the residual magnetism may be reversed by passing through the field winding a current opposite in direction to the original current.

Changing the direction of the current by reversing the main wires or otherwise, does not reverse the direction of rotation of any motor, since it reverses *both* the armature and the field. The way to reverse the direction of rotation is to reverse *either* the armature or the field connection *alone*, leaving the other the same as before.

Examination before Starting. The machine should be cleaned throughout, especially the commutator, brushes, electrical connections, etc. Any metal dust on the commutator or near electrical connections should be removed, as it is very likely to cause short circuits or grounds. Examine the machine carefully, and make sure that there are no screws or other parts that are loose or out of place. See that the oil-cups have a sufficient supply of oil, that the passages for the oil are clean, and that the feed is at the proper rate. In the case of self-oiling bearings, the rings or other means for carrying oil should work freely. See that the belt, if used, is in place, and that it has the proper tension. If the machine is being started for the first time, it should be turned a few times by hand, or run very slowly, in order to determine whether the shaft revolves easily and the belt runs on centers of pulleys.

The brushes should be carefully examined, and adjusted to make good contact with the commutator at the proper point, the switches connecting the machine to the circuit being left open. The machine should then be started with care, and brought up to full speed gradually, if possible. The person who starts either a dynamo or a motor should closely watch the machine and everything connected with it, and should be ready to throw it out of circuit and stop it instantly if the least thing seems to be wrong. He should then be sure to find out and correct the trouble before starting again.

Starting a Generator. A generator is usually brought up to speed either by starting its engine or other prime mover, or by connecting it to a source of power already in motion. The former should be attempted only by a person competent to manage steam engines or the prime mover in question. The mere mechanical connecting of a generator to a source of power is usually not difficult; but it should be done carefully and intelligently, even if it only requires throwing in a friction-clutch or shifting a belt from an idle pulley. To put a belt on a pulley in motion is difficult and dangerous, particularly if the belt is large or the speed is high; and should not be tried except by one who knows just how to do it. Even if a stick is used for this purpose, it is apt to be caught and thrown around by the machinery unless used in exactly the right way.

In many cases generators are brought to full speed before the brushes are put in contact with the commutator; but this is not necessary. If the brushes are in contact before starting, they can be more easily and perfectly adjusted, and the E. M. F. will come up slowly, so that any fault or difficulty will develop gradually and can be corrected, or the machine stopped, before any injury is done. In fact, if the machine is working alone on a system, and is absolutely free from any danger of short-circuiting any other machine or storage battery on the same circuit, it may be started while connected to the circuit, but not otherwise (see next article). With a large number of lamps connected to the circuit, the field magnetism and voltage might not be able to "build up" until the line is disconnected.

If one generator is to be connected to another or to a circuit having other generators or a storage battery working upon it, the greatest care should be taken. This coupling together of generators can be done perfectly, however, if the correct method is followed, but is likely to cause serious trouble if any mistake is made.

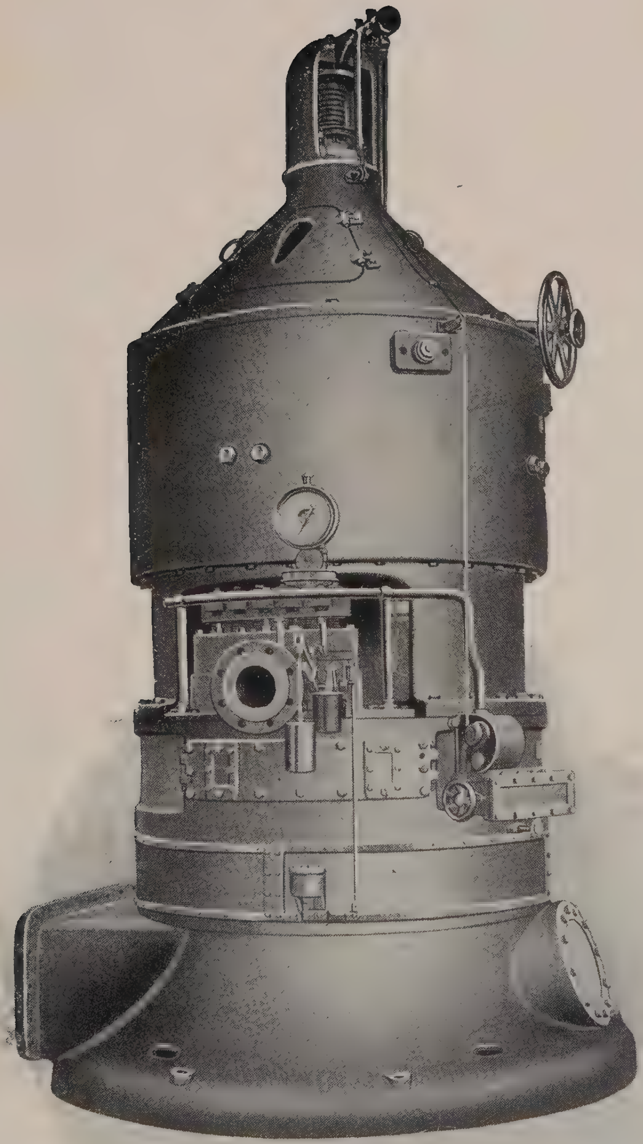
Two or more machines are often connected to a common circuit. This is especially the case in central stations where the load varies so much that, while one generator may be sufficient for certain hours, two, three, or more machines may be required at other times. The various ways in which this is done depend upon the character of the machines and of the circuit.

Generators may be connected together either in parallel or in series.

Generators in Parallel. In this case the + (positive or plus) terminals are connected together or to the same line, and the – (negative or minus) terminals are connected together or to the other line. The currents (*i. e.*, amperes) of the machines are thereby added, but the E. M. F. (volts) is not increased. The chief condition for the running of generators in parallel is that their voltages shall be equal, but their current capacities may be different.

For example: A generator producing 10 amperes may be connected to another generating 100 amperes, provided the voltages agree. Parallel working is therefore suited to constant-potential circuits. A generator to be connected in parallel with others or with a storage battery, must first be brought up to its proper speed, E. M. F., and other working conditions; otherwise it will short-circuit the system, and might burn out its armature. Hence it should not be connected to a circuit in parallel with others until its voltage has been tested and found to be equal to, or slightly (not over 1 or 2 per cent) greater than, that of the circuit. If the voltage of the dynamo is less than that of the circuit, the current will flow back through it and cause it to run as a motor. The direction of rotation is the same, however, if it is shunt-wound; and no great harm results from a slight difference of potential; but compound-wound machines require more careful handling.

Direct-Current Dynamos in Parallel are always Shunt-Wound (or Compound-Wound). The test for equal voltages may be made by first measuring the E. M. F. of the circuit and then of the machine by one voltmeter; or two voltmeters, one connected to each, may be compared (Fig. 18); or a differential voltmeter may be used. Another method is to connect the dynamo to the circuit through a high resistance and a galvanometer; and when the latter indicates no current, it shows that the voltage of the dynamo is equal to that of the circuit. A rougher and simpler way to do this is to raise the voltage of the dynamo until its "pilot-lamp," or other lamp fed by it, is fully as bright as the lamps on the circuit, and then to connect the dynamo to the cir-



500 Kw. CURTIS STEAM TURBINE.
Direct Connected to Continuous Current Generator

cuit. Of course the lamps compared should be intended for the same voltage and in normal condition. Be sure to connect the positive terminal of the dynamo to the positive conductor, and the negative terminal to the negative conductor (Fig. 18); otherwise there will be a very bad short circuit.

When the dynamo is first connected in this way, it should supply only a small amount of current to the circuit (as indicated by its ammeter), and its voltage should then be gradually raised until it generates its proper share of the total current; otherwise it will cause a sudden jump in the brightness of the lamps on the circuit.

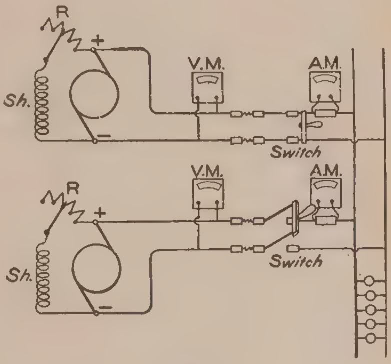


Fig. 18.

Series-Wound Dynamos in Parallel Not Used. If the machine is series-wound, the back current just described would cause a reversal of field magnetism and a very bad short circuit of double voltage. In fact, series dynamos in parallel are in unstable equilibrium, because if either tends to generate too little current, its own field, which is in series, is weakened, and thus still further reduces its current and probably will reverse the machine. This arrangement is therefore not used. One way in which this difficulty might be overcome is by causing each to excite the other's field magnet, so that if one generates too much current, it strengthens the field of the other and thus counteracts its own excess of power.

Another plan is to excite both fields by one machine, or, better, by both machines jointly, which is accomplished by connecting together the two + brushes and the two – brushes respectively, by the line and by what is called an **equalizer** (Fig. 19). In this way the electrical pressure at the terminals of the two armatures is made the same, and the currents in the two fields are also made equal. Series machines are not often run in parallel, but the principles just explained help the understanding of the next case, which is very important.

Compound Dynamos in Parallel. Since the field magnets of these machines are wound with series coils as well as with shunt coils, the coupling of them is a combination of the shunt and series cases just described.

The manner of connecting two or more compound dynamos to operate in parallel, is represented in Fig. 20, A being the armature, B the series, and C the shunt-field coils. R is the shunt-field rheostat; D and F are switches connecting the main terminals of the machine with the bus bars G and I, respectively; and E is a switch to connect the equalizer H with the brush end of the series coil B.

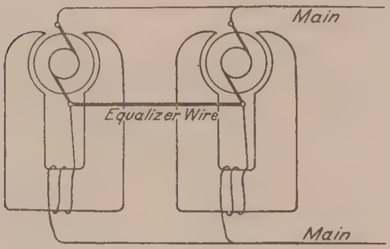


Fig. 19.

Assume that machine No. 1 is already in operation with its switches D, F, and E closed, and that it is desired to have machine No. 2 thrown in circuit. The procedure is as follows:

Bring machine No. 2 up to its rated speed, and adjust its pressure by means of the shunt-field rheostat until it is a little greater (about 1 per cent) than the difference of potential between the bars G and I. This fact may be ascertained by comparing two voltmeters connected to the dynamo and to the bus bars respectively; or by means of a single voltmeter connected through a double-throw switch, first to one and then to the other, which avoids the error due to a difference between two instruments. Another plan is to employ a differential voltmeter, that is, one having two windings on the movable coil, so that it indicates directly the difference in voltage between the two parts of the system.

After the pressure of the *incoming* dynamo has been properly regulated, the three switches E, F, and D are closed in the order named. If these points should be closed simultaneously by means of a triple-pole switch, a considerable current might flow through the series field winding, tending to increase still further the voltage of this dynamo, at the same time taking current away from the series coils of the other machines, and thereby reducing their potential. The shifting of the load thus produced might be so sudden and so great as to be objectionable. This action, however, is not of sufficient importance to overbalance the many advantages afforded by the use of a switch in which the three are combined as a triple-pole switch, thus guarding against the possibility of any accident due to closing the wrong circuit first.

After the machines have been thrown in parallel, their voltages should be adjusted by the shunt-field rheostats so that the load is properly divided between them.

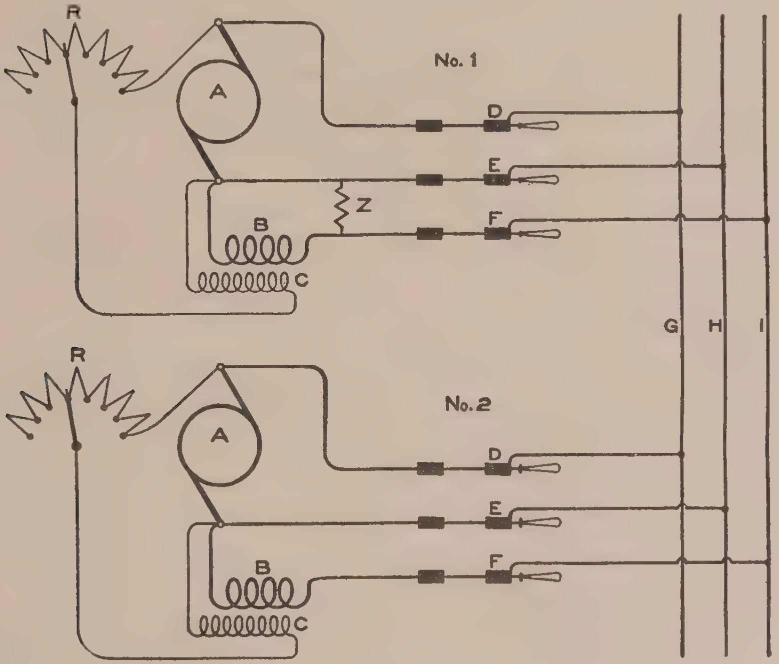


Fig. 20.

Compound dynamos of different size or current capacity may also be coupled as described, provided, of course, their voltages are equal; and provided also that the resistances of the series field coils, together with their leads to the bus bar, are inversely proportional to the current capacities of the several machines; that is, if a dynamo produces twice as much current, its series coil and lead should have half the resistance. It is further necessary that the two machines should agree in their action, so that a given increase in load will produce the same effect upon their voltages.

If they are not in agreement, they may be adjusted by slightly increasing the resistance of the series coil of that machine which tends to take too large a share of the load. This may be done by simply interposing a few extra feet of conductor of the same current capacity as the series coil, between the latter and the main conductor or bus bar. The shunts which are almost always used to adjust the effect of the series coils in compound dynamos (shown at Z in machine No. 1, Fig. 20), operate properly in the case of machines working *singly*, but are worthless for machines in parallel. The *resistances of the series coils themselves* must be adjusted as explained above, when two or more compound machines are run in parallel. The use of iron for this shunt makes the compounding effect in the dynamo more uniform, because its resistance, rising as the current through it increases, throws a greater fraction of the current through the series coils at full load, and compensates for the fact that the field magnetism, and consequently the voltage, does not increase proportionately with the increasing load current.

Shunt-wound dynamos run in parallel tend to steady each other, for, if one happens to run too fast, it has to do more work, which opposes the increase of speed ; and it also takes part of the load off the other machines, which makes them run faster, thus producing equality. This mutual regulation will take care of any slight difference between machines, such as that caused by the slip of the belt, or even small differences in the governing action of the different engines that may be driving them. Compound-wound dynamos have very much less mutual regulation, owing to the effect of the series coil ; and it is necessary that their speeds, voltages, etc., should regulate much more exactly than with simple shunt machines. They often work badly together owing to carelessness or to imperfect agreement between them, but with proper care and good apparatus they run well in parallel.

If generators are located at considerable distances from the switchboard, the equalizing connection may be run directly from one machine to the other with the equalizing switch (E, Fig. 20) on the frame of each, instead of running to the switchboard. This saves copper, especially in the case of large generators.

Alternators in Parallel. To run two alternators in parallel, several conditions have to be fulfilled: The incoming machine—as in the case of direct-current machines—must be brought up to nearly the same voltage as the first one; it must operate at exactly the same frequency; and, at the moment of switching in parallel, it must be in phase with the first machine.. This correspondence of frequency and phase is called **synchronism.**

It is impossible with mechanical speed-measuring instruments to determine the speed as accurately as is necessary for this purpose. There is, however, a very simple method of electrically determining small differences in speed or frequency. In Fig. 21, let M and N represent two single-phase alternators, which can be connected by means of the single-pole switch AB Across the terminals of the switch is connected an incandescent lamp L, capable of standing twice the voltage of either machine. When AB is open, the circuit between the machines is completed through L. The two machines may be connected in parallel as follows: Assuming machine M already in operation, bring up machine N to approximately the proper speed, and voltage; then watch lamp L. If machine N is running a very little slower or faster than machine M, the lamp L will glow for one moment and be dark the next. At the instant when the voltages are equal in pressure and phase, L will remain dark; but when the phases are displaced by half a period, the lamp will glow at its maximum brilliancy. Since the flickering of the lamp is dependent upon the difference in frequency, the machines should not be thrown in parallel while this flickering exists. The prime mover of the incoming machine must be brought to the proper speed; and the nearer machine N approaches snychronism, the slower the flickering. When it is very slow, we can use the moment the lamp is dark to throw the machines in parallel by closing the switch across AB. The machines are then in phase, and tend to remain so, since if one slows down the other will drive it as a motor. It is better to close the switch when the machines are approaching synchronism than when they are receding from it, that is, at the instant the lamp becomes dark.

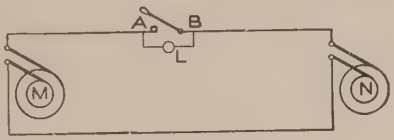


Fig. 21

This method of synchronizing is open to the following objections:

(*a*) The lamps may be dark with considerable difference in voltage. For instance, a 110-volt lamp is dark with a pressure of 20 to 25 volts.

(*b*) The lamp may be dark owing to a broken filament.

It may thus happen, with this arrangement, that the machines are placed in parallel while there is a considerable difference of voltage or phase existing, and an excessive rush of current will result.

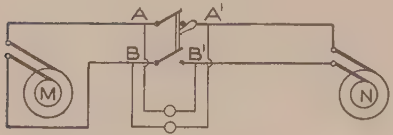


Fig. 22

A method not open to the above objections is shown in Fig. 22. The machines to be switched in parallel are each connected to the bus bars by means of double-pole switches. Two incandescent lamps, of the machine voltage, are cross-connected as shown. If the machines are in phase and the voltages generated are equal in value, the difference of potential between A and a given point is the same as that between A′ and the same point; likewise B and B′ have the same relative potential values. Hence a lamp connected between A and B′ would burn with the same brilliancy as if it were connected directly across AB; likewise with the other lamp. If, however, the machines happen to be directly opposite in phase but to be generating voltage of the same value, A and B′ are of the same relative potential value, and B and A′ are likewise of the same value; hence lamps cross-connected as in Fig. 22 would be dark. At any other phase difference the lamps will glow, but not so brightly as when in phase. Hence, with this arrangement, the machines should be thrown in parallel when the lamps are on the verge of maximum brightness, a condition readily determined, but not possible with the first method.

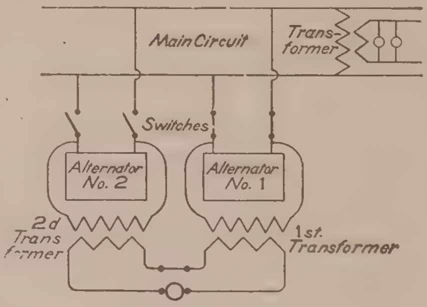


Fig. 23.

The connections as shown in Figs. 21 and 22 are not directly applicable to high-tension working, but require the introduction of transformers as shown in Fig. 23, which is a modification of Fig. 22. The secondaries (of, say, 50 volts each) should be connected in series with each other and to one 100-volt lamp. When the two machines are opposed in phase, the lamp is dim. If the lamp flickers badly, the phase is not right; but if the lamp is steady at full brightness, the machines are in phase, and they may be connected without disturbing the circuit, by closing the main switch.

If alternators are rigidly connected to each other or to the engine, so that they necessarily run exactly together, there is no need of bringing them into step each time, but they should be adjusted to the same phase in the first place.

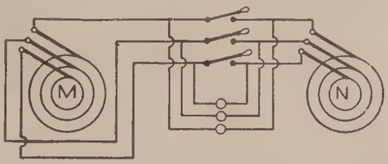


Fig. 24.

The connections of the synchronizing lamps of a three-phase system are similar to those for a single-phase system. For instance, the method employed in Fig. 21 may be extended, and lamps connected as in Fig. 24. If the three lamps simultaneously become dark or bright, the connections are correct, and the three switches may be closed at an instant of darkness. It may happen, however, that the lamps do not become bright or dark simultaneously but successively This indicates that the order of connection of the leads of one machine does not correspond with that of the other. In this case, transpose the leads of one machine until the proper or simultaneous action of the lamps is obtained. After the machines have been properly connected, it is sufficient to synchronize with one of the lamps. Similarly, with high-tension systems, only a single-phase transformer is required, connected as shown in Fig. 25.

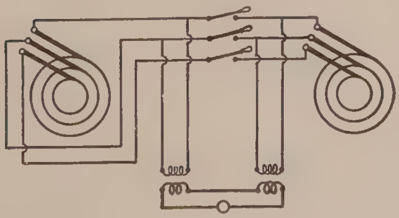


Fig. 25.

Generators in Series. This arrangement is less common than parallel working, and does not usually operate so well, except with series-wound machines on arc circuits, which is very successful. The conditions are exactly opposite to those in the preceding group—generators in parallel.

To connect machines in series, the positive terminal of one must of course be connected to the negative terminal of the next, and so on. Each must have a current capacity equal to the maximum current on the circuit, but they may differ to any extent in E. M. F. The voltages of machines in series are added together; and therefore danger to persons, insulation, etc., is increased in proportion.

Series-Wound Direct-Current Dynamos in Series are connected in the simple way represented in Fig. 26; but, usually machines connected in series are for arc lighting—for example, when two dynamos, each of 40 lights capacity, are run on one circuit of 80 lamps, in which case the dynamos usually have some form of regulator. These regulators do not usually work well together, because they are apt to "seesaw" with each other. This difficulty may be overcome either by connecting the regulators so that they work together, or by setting one regulator to give full E. M. F. and letting the other alone control the current. This latter plan can be followed only when the variation in load does not exceed the power of one machine. Constant-current dynamos having regulators with little inertia in the moving parts, and thus little tendency to "overshoot," such as the Brush machine, can be run in series without much trouble.

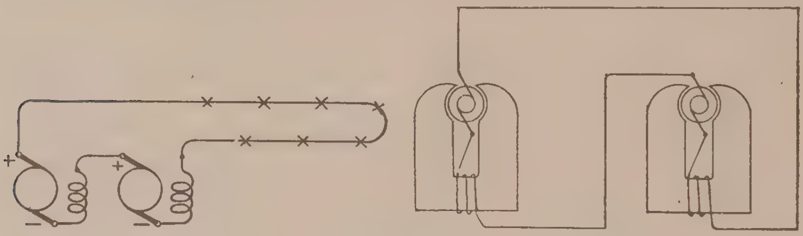


Fig. 26.

Shunt or Compound Dynamos in Series run well, provided the shunt-field coils are connected together to form one shunt across both machines. If the machines are compound, all of the series coils must be connected in series with the main circuit. Another plan is to connect each shunt field so that it is fed only by the armature of the other machine ; or both the shunt coils may be connected so as to be fed by one armature, the series coils being in the main circuit as before.

Alternators in Series. The synchronizing tendency which makes it possible to run alternators in parallel, causes them to get out of step and become opposed to each other when it is attempted to run them in series. It is therefore impracticable to run them in series unless their shafts are rigidly connected so that they must run exactly in phase and thus add their waves of current instead of counteracting each other. This case rarely occurs.

Dynamos on the Three-Wire System (Direct-Current). In the ordinary three-wire system for incandescent lighting and power service, no particular precautions are required in starting or connecting the machines; and either of the two arrangements shown in Figs. 27*a* and 27*b* may be adopted. The two sides of the system are almost independent of each other, and form practically separate circuits, for which the middle or neutral wire acts as a common conductor. There is, however, a tendency for the dynamos (Fig. 27*a*) to be reversed in starting up, in shutting down, or in the case of a severe short circuit. This can be avoided by exciting the field coils of all the dynamos from one side of the system, or from a separate source. To obtain good regulation, it is necessary to balance the load equally on both sides of the system. It is advisable to employ 220-volt motors on 110-volt 3-wire systems, and to connect them across the outside conductors so that the motor load shall not unbalance the system.

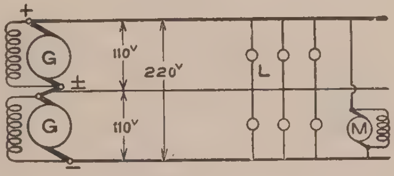


Fig. 27*a*.

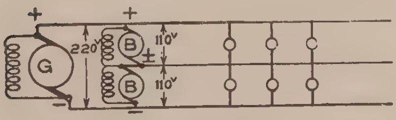


Fig. 27*b*.

KINDS OF MOTORS, CONNECTIONS, AND STARTING.

The general instructions relating to the adjustment of brushes, screws, belt, oil-cups, etc., given in relation to the generator, should be carefully followed preparatory to starting a motor. The actual starting of a motor is usually a simple matter, since it consists merely in operating a switch; but in each case there are one or more important points to be considered

CONSTANT-POTENTIAL D. C. CIRCUITS.

Shunt-Wound Motor. A motor to operate at nearly constant speed, with varying loads, on a D. C. constant-potential system (110- or 220-volt lighting circuits) is usually plain shunt-wound. This is the commonest form of stationary motor. The field coils are wound with wire of such a size as to have the proper resistance and resulting magnetizing current; and since the potential applied is practically constant, the field strength is constant.

In starting shunt motors, no trouble is likely to occur in connecting the field to the circuit. The difficulty is with the armature current, because the resistance of the armature is very low in order to get higher efficiency and constancy of speed, and the rush of current through it in starting might be twenty or more times the normal number of amperes. To avoid this excessive current, motors are started on constant-potential circuits through a rheostat or "starting-box" containing resistance coils.

The main wires are connected through a branch cut-out (with safety fuses), and preferably also a double-pole knife switch Q, to the motor and box, as indicated in Fig. 28. When the switch Q is closed, the arm S being in its left-hand position, the field circuit is closed through the contact stud *f*, and the armature circuit is closed through the resistance coils *a*, *a*, *a*, which prevent the rush of current referred to. The motor then starts, and as the speed rises it generates a counter E. M. F., so that the arm S can be turned as shown until all the resistance-coils *a*, *a*, *a*, are cut out, and the motor is directly connected to the circuit and running at full speed. The arm S should be turned slowly enough to allow the speed and counter E. M. F. to come up as the resistances *a*, *a*, *a* are cut out. The arm S should positively close the field circuit first, so that the magnetism reaches its full strength (which may take several seconds) before the armature is connected.

In the arrangement shown in Fig. 28 the release magnet has its coils in series with the field. As long as the motor is in operation, the core is energized and the arm S is held in the position shown. If, however, the current supplied to the motor is cut off and the motor comes to rest, the core of the magnet loses its attractive force, and the arm S is released, being automatically moved back to the starting position by a spring.

The coils *a*, *a*, *a* are made of comparatively fine wire, which can carry the current only for a few seconds in a "starting-box;"

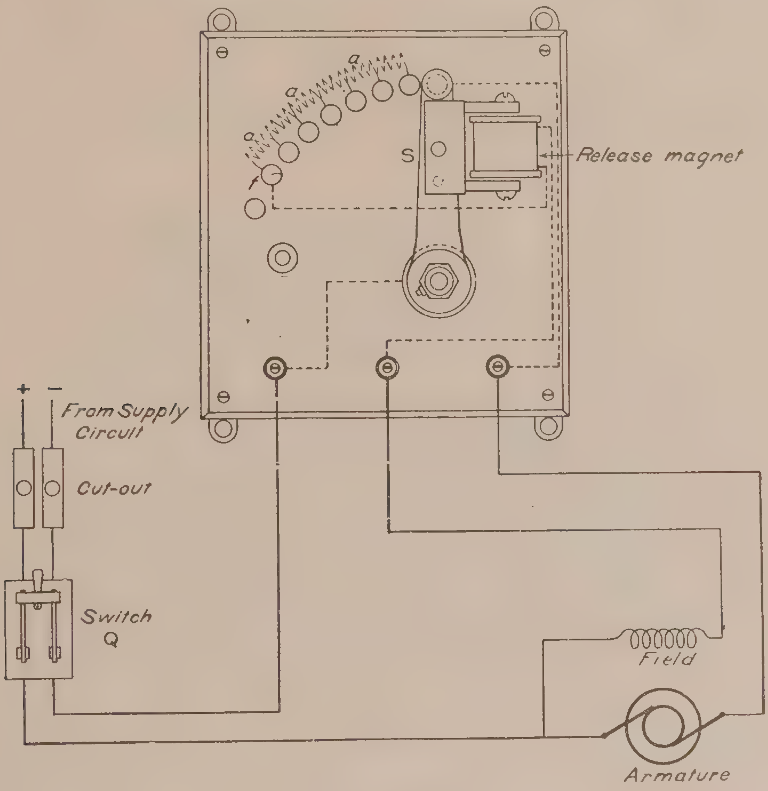


Fig. 28.

but if the wire is large enough to carry the full current continuously, it is called a "regulator," because the arm S may be left so that some of the resistances *a*, *a*, *a* remain in circuit, and they will have the effect of reducing the speed of the motor, which is often very desirable.

In some cases where a circuit is used exclusively for a single motor, the speed is regulated without heavy resistances by varying the E. M. F. of the dynamo which supplies the circuit. The dynamo regulator is then placed near the motor. The advantage is that the regulator is not compelled to control a heavy current, but a special circuit of unvaried pressure must be provided to keep the field of the motor constant.

The speed control of a shunt motor may be simply obtained as follows:

a. For lower speeds, insert resistance in series with the armature circuit. The resulting I. R. drop reduces the value of the voltage applied to the armature terminals, and thus reduces the speed.

b. For higher speeds, insert resistance in the shunt-field circuit. This reduces the magnetic flux, and to generate the same C. E. M. F. the motor must speed up.

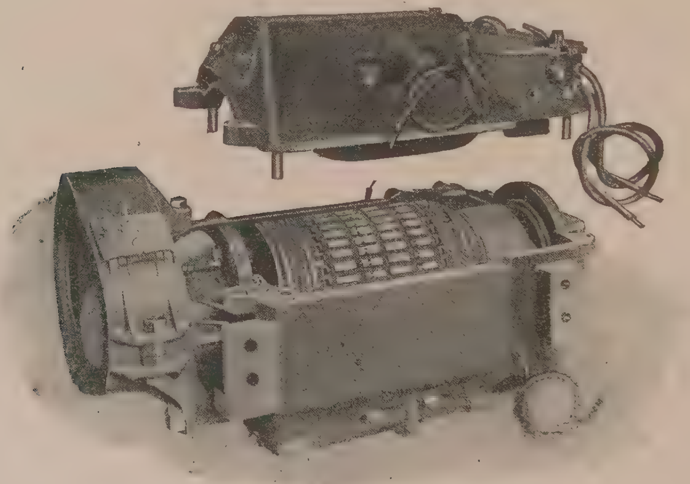


Fig. 29.

The field circuit of a shunt motor should never be opened while pressure is still applied to the armature terminals, as under these conditions the armature current becomes very excessive and the armature is likely to race and probably be damaged. A moderate decrease in field strength only is allowable ; otherwise sparking becomes excessive.

Series-Wound Motor. The ordinary electric railway motor on the 550-volt trolley system is the chief example of the class (Fig. 29.) Motors for fans, pumps, or electric elevators and hoists are either of this kind or of the compound type. A rush of current tends to occur when the series type of motor is started, similar to that in the case just described; but it is less, because the field-coils are in series, so that their resistance and self induction reduce the excess. Furthermore, the counter E. M. F. is greater even at low speed because the heavy current produces a strong field.

The connections as indicated in Fig. 30 are very simple, the armature, field-coils, and rheostat all being in series and carrying the same current.

The series-wound motor on a constant-potential circuit does not have a constant field strength, and does not tend to run at constant speed, like a shunt motor. In fact it may "race" and tear itself apart if the load is taken off entirely; it is therefore suited only to railway, pump, fan, or other work where variable speed is desired, or where there is no danger of the load being removed or a belt slipping off. It is also used where the potential is subject to sudden and large drops, as on the ends of long trolley circuits, because in such a case a shunt motor becomes momentarily a generator and sparks very badly. The fields of series motors are sometimes "overwound," that is, so wound that they will have their full strength with even one-half or one-third of the normal current. The objects are to secure a nearly constant speed with varying loads, to enable the motor to run at high efficiency when drawing small currents, and to prevent sparking at heavy loads.

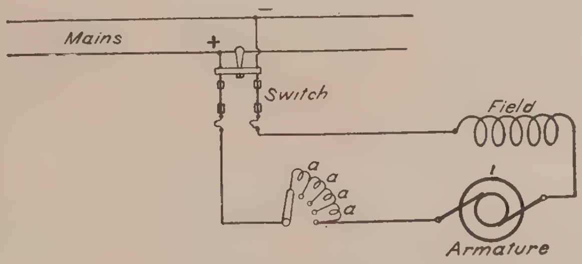
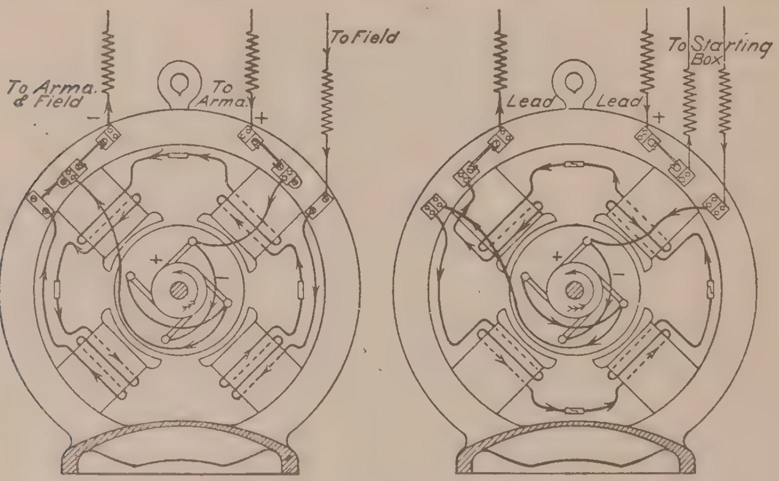


Fig. 30.

In multipolar motors having more than two field-coils, the coils are all connected together, and are equivalent to the single pairs of coils shown in the several diagrams. Being separated, however, it is sometimes necessary to trace out the connections. Fig. 31 represents the necessary connections for a four-pole motor, shunt-wound and series-wound.

Differentially-Wound Motor. This is a shunt-wound motor with the addition of a coil of large wire, on the field, connected in series with the armature in such a way as to oppose the magnetizing effect of the shunt winding and weaken the field, thus causing the motor to speed up when the load is increased, as an offset to the slowing-down effect of load.

It was formerly used, for obtaining very constant speed, but it has been found that a plain shunt motor is sufficiently constant for almost all cases. The differential motor, if overloaded, has the great disadvantage that the current in the opposing (series) field-coil becomes so great as to kill the field magnetism; and instead of increasing or keeping up its speed, the armature slows down or stops, and is likely to burn out; whereas a plain shunt motor can increase its power greatly for a minute or so when overloaded, and will probably throw off the belt or carry the load until the latter decreases to the normal amount.



Shunt-wound Motor. Series-wound Motor.

Fig. 31.

Compound-Wound Motor. This type of motor is also provided with a shunt and a series-field winding, Fig. 32, but in this instance they magnetize the field in the same direction, or, in other

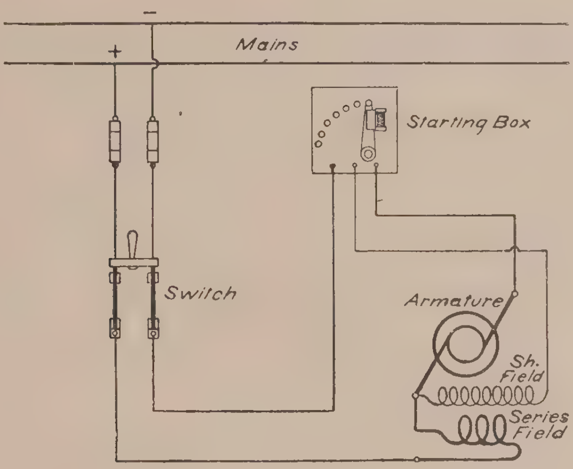


Fig. 32.

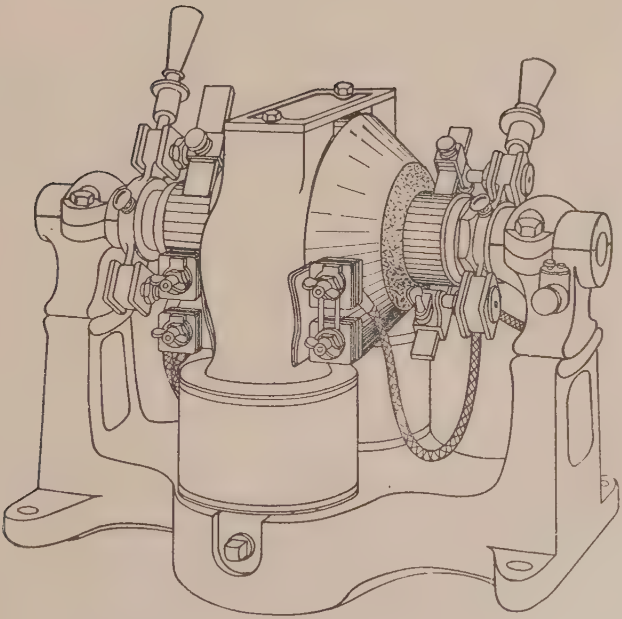


Fig. 33.

words, their effect is cumulative. This type of motor possesses the powerful starting torque feature of the series motor, but a less variable speed with varying loads. It is employed where a great starting torque and a fairly uniform running speed are required, as, for example, with electric hoists or elevators.

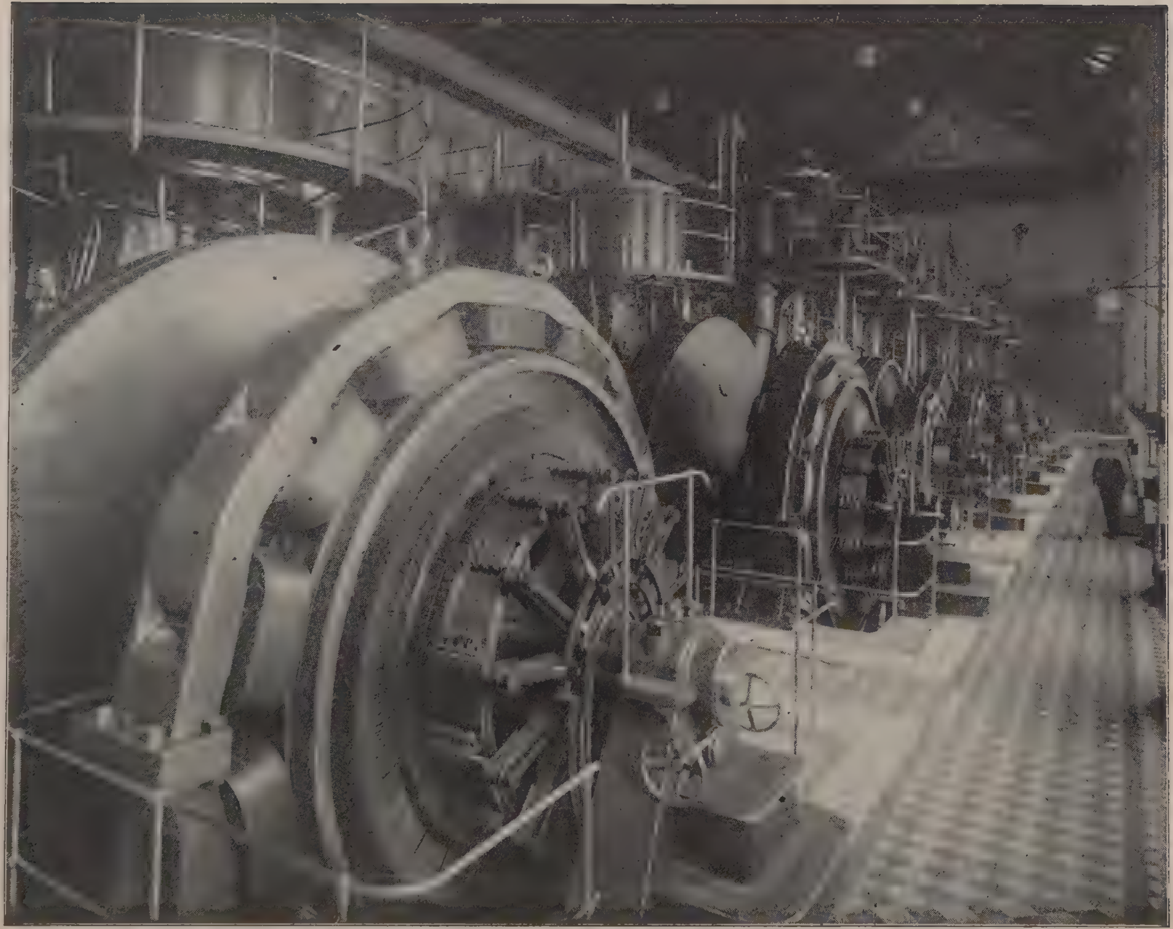
Dynamotors, Fig. 33, and also motor-generator sets, are started in the same way as motors ; that is, the motor portion of the machine is connected to the circuit and operated precisely like the corresponding kind of motor. Usually the motor part is plain shunt-wound, and is supplied with current from a constant-potential circuit. It is therefore connected and started in the manner shown and described on page 40.

The current generated by the dynamo portion of the dynamotor may be taken from the terminals, and used for any purpose to which it is suited. The E. M. F. or current produced may be regulated by varying the resistance in the armature circuit of either the motor or dynamo. In case the dynamo armature has a separate field magnet, the E. M. F. and current may be controlled by regulating the magnetic strength of this field, or the machine may be compounded or even "over-compounded." But if the armatures of both motor and dynamo are acted upon by the same field, the E. M. F. of the dynamo cannot be varied except by inserting resistances in the circuit of either armature or by shifting the brushes. But the latter method will be likely to cause sparking.

ALTERNATING-CURRENT MOTORS.

Alternating-current motors operate on constant-potential circuits, since almost all A. C. systems are of this kind. There are several types of these motors, the simplest of which is the *series machine* for single-phase current. This is similar to the corresponding D. C. motor, except that its field must be laminated.

It possesses the characteristic of large starting torque and lends itself to variable speed control like its direct current counterpart and is coming into use very rapidly for electric railway work. Both the General Electric and the Westinghouse Electric and Manufacturing Companies have placed such machines upon the market and they are already in operation on a number of electric roads where they are giving satisfaction.



Hamburg Central Power Station

Hamburg, Germany

This type of motor while retaining practically all the advantages of the direct-current series motor for electric railway work permits the use of alternating current on the trolley with all its attendant advantages. A frequency of 25 seems likely to become the standard for such work. The cars can be operated on existing direct-current lines and the multiple unit control system can be applied to cars equipped with single-phase motors.

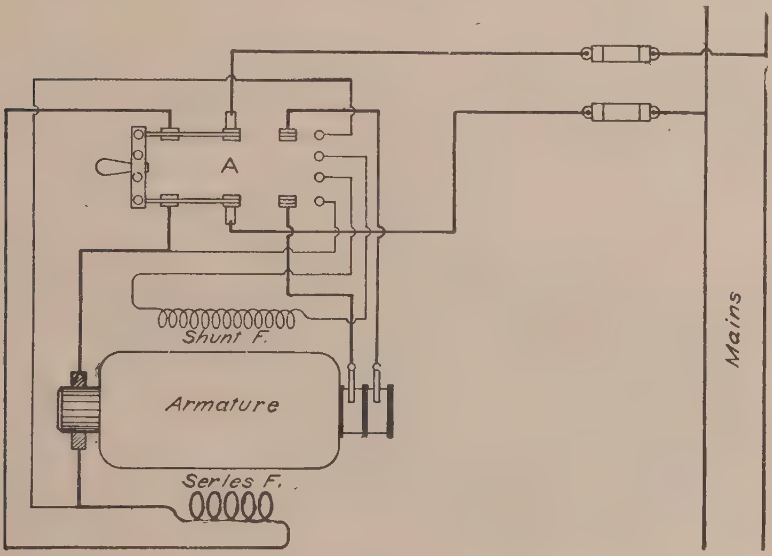


Fig. 34.

An ordinary single-phase alternator can be used as a motor; but it must first be brought up to synchronism with the supply generator by means of some auxiliary starting device (steam engine, polyphase induction motor, etc.) before the load can be applied. In this form the machine is known as the *single-phase synchronous motor.* The condition of synchronism is determined by one of the methods described in the paragraph on "Alternators in Parallel." After the motor is in synchronism it may be connected to the circuit by closing its supply switch; and it will then continue to run at an absolutely constant speed, unless heavily overloaded, when it falls out of step and stops.

On account of these features, the synchronous motor is not to be recommended for general application. Various manufacturers, notably the Wagner Electric Company, and the Fort Wayne Electric Company, manufacture self-starting, single-phase synchronous motors, usually limited, however, to the smaller sizes. The construction and action of the Fort Wayne motor (Fig. 34), which is a combination of the two preceding types, are as follows: The armature core is provided with a double winding, one equipped with collecting rings, and the other with an ordinary commutator. The field magnet, which is laminated, is wound with two separate circuits, one being of low resistance and a small number of turns, the other of high resistance and many turns, like an ordinary shunt-field winding. In starting, the motor runs as a series machine, the low-resistance field being in series with the commutated armature winding and the line. When it has reached synchronism, the switch A, on the top, is thrown over to the right, and the supply line connected with the collector rings and the corresponding armature winding; while the commutated end is connected to the other field winding, and thus provides the direct current necessary for field excitation.

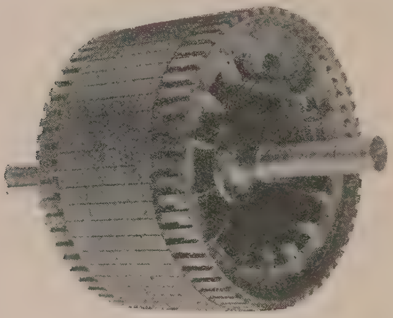


Fig. 35.

In addition to the single-phase there is also the *polyphase synchronous motor.* This latter form, however, is self-starting without field current, but will not carry a load until it is running in synchronism. When this condition is reached, the field circuit should be closed before applying the load.

A great advantage of the synchronous motor is that when its field is over-excited, it draws a leading current from the line, thus acting like a condenser and tending to neutralize the inductive effect of other machinery, so that the power factor of the whole system is raised. The most extensive use of the synchronous motor is as a part of the rotary converter, which is employed to convert alternating into direct currents, for traction and electro-chemical purposes.

The satisfactory use of alternating currents for power purposes depends mainly on the *polyphase induction motor*, as in this form the A. C. motor is self-starting with considerable torque and operates at a practically constant speed from no load to a heavy overload. Induction motors are designed for the standard voltages and frequencies.

In most induction motors now built, the primary, or part into which the currents from the line are led, is the stationary member, or *stator*. The secondary, in which the induced currents are set up, is the rotating member, or *rotor*. There are two kinds of rotor windings, the simpler being that known as the "squirrel-cage." This winding is made up of a number of copper bars, equally spaced around the rotor core, and imbedded therein. The terminals of these inductors are interconnected, or short-circuited, by means of heavy copper rings placed at both ends of the core, as shown in Fig. 35.

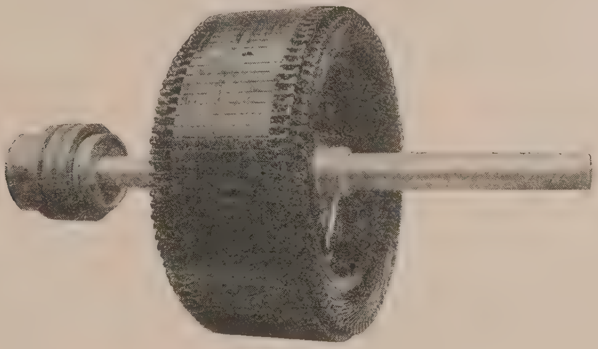


Fig. 36.

The other form of winding is of the drum species, usually three-phase, Y-connected; and the coils are located at 120° intervals (the arc between centers of adjacent poles being called 180°) with respect to each other. The free ends of the windings are respectively brought out to three slip or collecting rings ; and on this account this type of rotor is frequently called the "slip-ring" rotor (Fig. 36).

Starting Induction Motors. In small sizes, up to 3 or 5 H. P., the induction motor can be started by connecting its stator terminals directly to the line. But with larger sizes the inrush of current is excessive and likely to disturb the system ; accordingly some form of starting device is usually necessary.*

Starting Compensators. This inrush of current can be avoided by inserting a starting resistance, or inductance, in series with the primary winding and the line, or by using some other means of cutting down the applied E. M. F. The torque of an induction motor decreases as the square of the applied voltage, so that this method of starting results in a greatly reduced starting effort. However, in many instances, motors are not started up under full load, so that this may not be a serious objection.

While a resistance could be employed as described, it is more economical to employ an auto-transformer (that is, a transformer having but one coil, which serves as both a primary and a secondary), or *compensator*, as it is called when used for this purpose Compensator connections for a three-phase motor are represented in Fig. 37. The compensator consists of coils *a*, *b*, and *c*, wound on a laminated-iron core, each coil being provided with a number of taps, 1, 2, 3, etc. The pressure applied to the motor at starting is proportioned to the amount of each coil included in the circuit. While the compensator winding is provided with taps, only that one which is most suitable for the work is used after the equipment is permanently installed. When the switch is in the

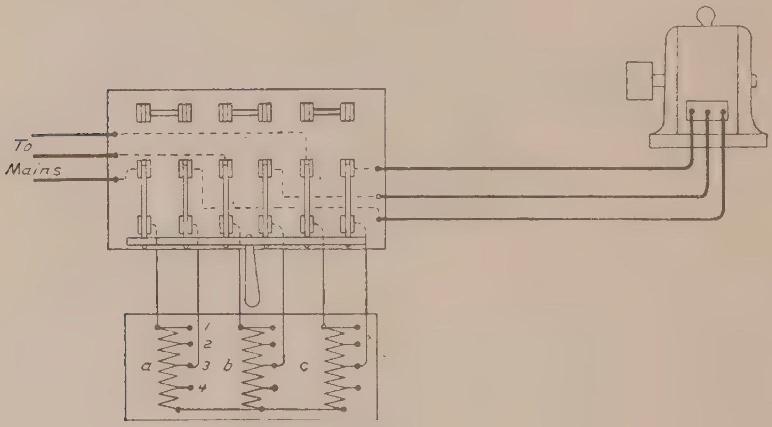


Fig. 37.

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* This inrush of current is frequently three times the rated load current.

lower position as indicated, a part of each coil is in series with each leg of the system leading to the motor; and the applied voltage is correspondingly cut down. After the motor reaches its rated speed, the switch is thrown to the upper or running position, and the stator or primary terminals are connected directly to the line. The compensator thus prevents an excessive inrush of current, and gives the motor a smooth start, although it decreases the starting torque, compared with that due to full line pressure.

Speed Regulation of Induction Motors. For some classes of work, it is desirable to have induction motors arranged so that their speed can be controlled, the usual methods being:

a. The insertion of a variable resistance in the rotor circuit.
b. Cutting down the voltage applied to the stator, as just described.

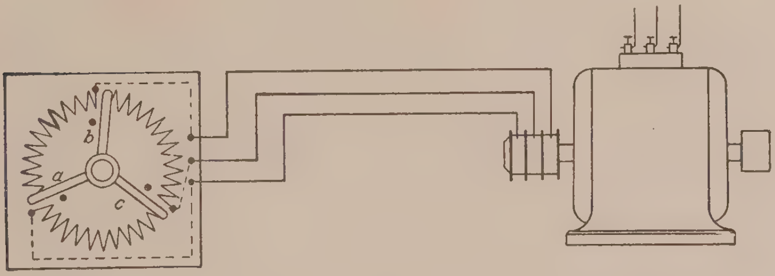

Fig. 38.

The more satisfactory method of speed control, is that with variable resistance inserted in the rotor circuit, the power-factor and hence the efficiency of the system being greater at reduced speeds than with the compensator or equivalent device. It requires, however, the use of collector rings, connecting brushes, and leads, since a resistance for continuous service is too bulky to be placed within the machine. Still further, the heat developed in the resistance would heat the machine too much. The controller itself looks like an ordinary trolley car controller, but for simplicity it is represented as a three-armed controller (Fig. 38) in which the arms *a*, *b*, and *c* are in electrical contact under the handle. The resistance is provided in three sets, one for each free end of the rotor winding; and each set is subdivided so that it can be gradually cut out of circuit as the motor speed increases. Frequently the controller is so arranged that the first motion of the handle closes the supply lines, and subsequent motions vary the resistances in the rotor circuit, thus performing the function of a supply switch and speed controller.

Another method of speed control, is to have the winding on the stator arranged so that by means of a suitable controlling switch, the number of poles can be changed. This is a very economical method from the electrical standpoint, and gives a very wide range of control, but, on account of its complexity and cost, is used only to a limited extent.

In general, the induction motor does not allow of the same range of speed control as does the direct-current motor, and the methods employed for this purpose are not efficient.

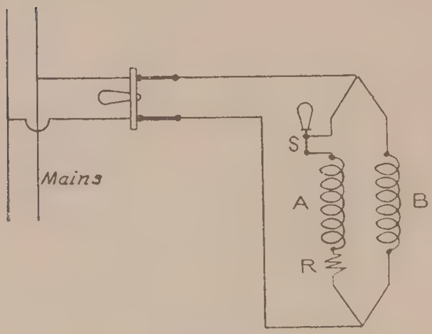

Fig. 39.

Single-Phase Induction Motor. A two or three-phase induction motor will operate fairly well, if, after reaching full speed, all but one of the phases be cut out. It will not however start from rest under the influence of single-phase excitation. Hence, to start an induction motor from the lines of a single-phase system, currents differing in phase must be obtained. This is accomplished by connecting the two primary windings A and B (in the case of a two-phase motor) in parallel to the single-phase mains, at the same time connecting in series with one winding a resistance R (Fig. 39). The currents flowing through these two windings will then differ in phase, one leading the other on account of a difference in their constants, and will thus produce a rotating field, and the motor will then start up.* When the motor has reached full speed, one phase may be cut out by opening the switch at S, and the machine will carry its load. The resistance R may be replaced to advantage by a condenser, especially on small machines. Such a machine is commonly called a "split-phase" motor.

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* This field is not a rotary field in the full sense, being elliptical in character.

DIRECTIONS FOR RUNNING GENERATORS AND MOTORS.

After any one of these machines has been properly started, it usually requires little attention while running; in fact, generators or motors frequently operate all day without any care whatever.

In the case of a machine that has not been run before or has been changed in any way, it is wise to watch it closely at first. It is also well to give the bearings of a new machine plenty of oil at first, but not enough to run on the armature, commutator, or any part that would be injured by it; and to run the belt (if used) rather slack until the bearings and belt are in easy working condition.

If possible, a new machine should be run without load or with a light one for an hour or two, or for several hours in case of a large machine; and it is bad practice to start a new machine with its full load or even a large fraction of it. This is true even if the machine has been fully tested by its manufacturer and is in perfect condition, because there may be some fault in setting it up or some other circumstance that would cause trouble. All machinery requires some adjustment and care for a certain time to get it into smooth working order.

When this condition is reached the only attention required is to supply oil when needed, keep the machine clean, and see that it is not overloaded. A generator requires that its voltage or current should be observed and regulated if it varies. The attendant should always be ready and sure to detect the beginning of any trouble, such as sparking, heating, noise, abnormally high or low speed, etc., before any injury is caused, and to overcome it. Such directions should be pretty thoroughly committed to memory in order promptly to detect and remedy any trouble when it occurs suddenly, as is usually the case. If possible, the machine should be shut down instantly when any indication of trouble appears, in order to avoid injury and give time for examination.

Keep all tools or pieces of iron or steel away from the machine while running, as they might be drawn in by the magnetism, perhaps getting between the armature and pole pieces and ruining the machine. For this reason use a zinc, brass, or copper oil-can instead of one of iron or "tin" (tinned iron)

Particular attention and care should be given to the commutator and brushes, to see that the former keeps perfectly smooth and that the latter are in proper adjustment. (See "Sparking.")

Never lift a brush while the machine is delivering current unless there are one or more other brushes on the same side to carry the current, as the spark might make a bad burnt spot on the commutator, or might burn the hand.

Touch the bearings and field coils occasionally to see whether or not they are hot. To determine whether the armature is running hot, place the hand in the current of air thrown out from it by centrifugal force.

Special care should be observed by any one who runs a generator or motor, to *avoid overloading* it, because this is the cause of most of the troubles which occur.

Personal Safety. Never allow the body to form part of a circuit. While handling a conductor, a second contact may be made accidentally through the feet, hands, knees, or other part of the body, in some peculiar and unexpected manner. For example, men have been killed because they touched a "live" wire while standing or sitting upon a conducting body.

Rubber gloves or rubber shoes, or both, should be used in handling circuits of over 500 volts.* The safest plan is not to touch any conductor while the current is on; and it should be remembered that the current may be present when not expected, owing to an accidental contact with some other wire or to a change of connections. Tools with insulated handles, or a dry stick of wood, should be used instead of the bare hand.

The rule to use *only one hand* when handling dangerous electrical conductors or apparatus is a very good one, because it avoids the chance, which is very great, of making contacts with both hands and getting the current through the body. This rule is often made still more definite by saying, "Keep one hand in your pocket," in order to make sure not to use it. The above precautions are often totally disregarded, particularly by those who have become careless through familiarity with dangerous currents. The result has been that *almost all persons accidentally killed*

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* These articles should be subjected to tests at frequent intervals, so as to determine their condition.

by artificial electricity have been experienced linemen or station men.

Stopping Generators or Motors. This is accomplished by following substantially the same directions as for starting them, but in the reverse order.

A generator operating alone on a circuit can be slowed down and stopped without touching the switches, brushes, etc., in which case the current gradually decreases to zero; and then the connections can be opened without sparking or any other difficulty.

However, when a generator is operating in parallel with others, or with a storage battery, it must not be stopped or reduced in speed, until it is entirely disconnected from the system, otherwise it will act as a short circuit. Furthermore, the current generated by it should be reduced nearly to zero before its switch is opened. This is accomplished by adjusting the field rheostat of the machine to be cut out, great care being taken that the change is gradual. If the reduction be rapid, the voltage of the machine may drop so low as to cause a back current to flow.

A **constant-current generator** may be cut into or out of circuit in series with others, and can be slowed down or stopped; or its armature or field coils may be short-circuited to prevent the action of the machine, without disconnecting it from the circuit. *It is absolutely necessary, however, to preserve the continuity of the circuit*, and not to attempt to open it at any point, as this would produce a dangerous arc. Hence a by-path must be provided by closing the main circuit around the generator, before disconnecting it. This same rule applies to any lamp, motor, or other device on a constant-current system.

Never, except in an emergency, should any circuit be opened when heavily loaded, for the reason that the flash at the contact points, discharge of magnetism, and mechanical shock which result, are decidedly objectionable.

A Constant-Potential Motor is stopped by turning the starting-box handle back to the position it had before starting (Fig. 28); or, *if there is a switch Q, connecting the motor to the circuit*, as there always should be, it should be opened, after which the starting-box handle is moved back to be ready for starting again.

Immediately after a machine is stopped, it should be thoroughly cleaned, and put in condition for the next run. When not in use, machines should, when feasible, be protected from dirt and moisture by covers of some waterproof material.

INSPECTING AND TESTING.

Adjustment and the other points which depend merely upon mechanical construction, are hardly capable of being investigated by a regular quantitative test, but they can and should be determined by thorough inspection. In fact a very careful examination of all parts of a machine should always precede any test of it. This should be done for two reasons: first, to get the machine into proper condition for a fair test; and, second, to determine whether the materials and workmanship are of the best quality and satisfactory in every respect. A loose screw or connection might interfere with a good test; and a poorly fitting bearing, brush-holder, or other part might show that the machine was badly made.

If it is necessary to take the machine apart for cleaning or inspection, the greatest care should be exercised in marking, numbering, and placing the parts, in order to be sure to get them together exactly the same as before. In taking a machine apart or putting it together, only the minimum force should be used. Much force usually means that something wrong is being done. A wooden or rawhide mallet is preferable to an iron hammer, since it does not bruise or mar the parts. Usually screws, nuts, and other parts should be set up fairly tight, but not tight enough to run any risk of breaking or straining anything. Shaking or trying each screw or other part with a wrench or screw-driver, will show whether any of them are too loose or otherwise out of adjustment.

Friction. The friction of the bearings and brushes can be tested roughly by merely revolving the armature by hand, or slowly by power, and noting if it requires more than the normal amount of force. Excessive friction is quite easily distinguished, even by inexperienced persons. Another method is to revolve the armature by hand or otherwise, and see if it continues to revolve by itself freely for some time. A well-made machine in good condition and running at or near full speed, will continue to run for several minutes after the turning force is removed.

A method for actually measuring the friction consists in attaching a lever (a bar of wood, for example) to the shaft or pulley at right angles to it. The force required to overcome the friction and to turn the armature without current, is then determined by known weights or, more conveniently, by an ordinary spring balance. For convenience in dividing by the length of the lever, etc., to determine the value of the friction compared with the power of the machine, it should be exactly 1, 2, or 4 feet long. The friction of the bearings alone—that is, the pull which is required to turn the armature when the brushes are lifted off the commutator—should not exceed about 2 per cent of the total torque or turning force of the machine at full load. When the brushes are in contact with the commutator with the usual pressure, the friction should not then exceed about 3 per cent; that is, the brushes themselves should not consume more than 1 per cent of the total turning force.

Another method of measuring the friction of a machine is to run it by another machine used as a motor, and determine the volts and amperes required, first, with brushes lifted off, and second, with brushes on the commutator with the usual pressure. The torque or force exerted by the driving machine is afterwards measured by a Prony brake in the manner described hereafter for testing torque, care being taken to make the Prony brake measurements at exactly the same volts and amperes as were required in the friction tests. In this way the torques exerted by the driving machine to overcome friction in each of the first two tests are determined; and these torques, compared with the total torque of the machine being tested, should give percentages not exceeding those stated above for maximum values of friction. The magnetic pull of the field on the armature may be very great if the latter is not exactly in the center of the space between the pole pieces. This would have the effect of increasing the friction of the shaft in the bearings when the field is magnetized. It occurs to a certain extent in all cases, but it should be corrected if it becomes excessive. This may be tested by turning the current into the fields, being sure to leave the armature disconnected, and then turning the shaft with the lever as before. The friction in this case should not be more than 2 to 4 per cent.

Tests for friction alone should be made at a low speed, because at high speeds the effects of Foucault currents and hysteresis enter and materially increase the apparent friction.

Balance. The perfection of balance of the armature or pulley can be roughly tested by simply running the machine at normal speed and noting if these parts cause any objectionable vibration. Of course, practically every machine produces perceptible vibration when running, but this should not amount to more than a very slight trembling. The balance of a machine can be definitely tested, and the extent of the vibration measured, by suspending the machine or by mounting it on wheels, and running it at full speed. In this case it is better to run the machine as a motor, even though it be actually a generator, in order to avoid the necessity of running it by a belt, which would cause vibration and interfere with the test. If, however, the use of a belt is unavoidable, it should be arranged to run vertically upward or downward so as not to produce any horizontal motion in addition to the vibration of the machine itself. Fig. 40 shows a machine hung up to be tested for balance, and run either as a motor or by the vertical belt indicated by the dotted lines. Any lack of balance will cause the machine to vibrate or swing horizontally, and this motion can be measured on a fixed scale.

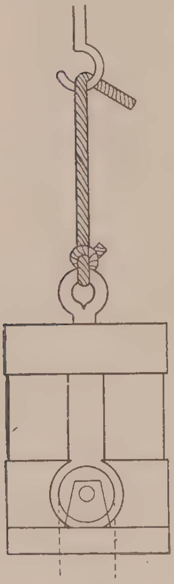

Fig. 40.

Noise. This cannot well be tested quantitatively, although it is very desirable that a machine should make as little noise as possible. Noise is produced by various causes. The machine should be run at full speed, and any noise and its cause carefully noted. A machine—especially the commutator—will nearly always run more quietly after it has been in use a week or more and has worn smooth.

Heating. The proper way to determine the temperature rise in electrical apparatus is by measurements of resistance, before and after operating for a specified time (usually 3 to 4 hours) under rated load.

The rise of temperature is:

$$\theta = (238.1 + t)\left(\frac{(R_t + \theta}{R_t} - 1\right),$$

in which t is the room temperature in degrees Centigrade, R_t the resistance in ohms at room temperature, and $(R_t + \theta)$ the final resistance at a temperature elevation of θ° C. The standard room temperature is 25° C; and if it differs from this, the determined rise should be corrected by $\mp\frac{1}{2}$ per cent for each degree C. For ordinary tests it may be assumed that the resistance of copper increases .4 per cent for each degree C rise in temperature. The allowable rise in temperature for field or armature windings is 50° C, hence their resistance for continuous operation at rated load should not be more than 20 per cent in excess of the room temperature. The heating of commutators, collector rings, and brushes that cannot be measured electrically, is tested by thermometers when the machine is stopped, the permissible rise being 50° C; and for bearings and other parts of machines the limit is 40° C. When a thermometer is applied to a surface it should be covered by a pad of cotton or waste cloth, in a shallow, circular box about $1\frac{1}{2}$ inches in diameter. A large pad tends to accumulate heat. When machines are in operation, or in other cases when it is not convenient to measure resistances, especially for excessive temperatures due to abnormal conditions, thermometers may be used to test all stationary parts; but it should be noted that their indications are usually about 5° C lower than those determined by resistances, because the surface is cooler than the interior. A very simple test of heating is to apply the hand to the armature, etc., and if it can be held there without great discomfort, the temperature is not dangerous. Allowance should always be made, however, for the fact that, on account of its heat conductivity, bare metal feels very much hotter than cotton-covered wires, cloth, etc., at the same actual temperatures; but this apparent difference is much less if the hand is kept on for 10 to 20 seconds.

Sparking at the commutator cannot be accurately measured; but it is very objectionable, and in a machine in good order should be hardly perceptible. In any test one should observe carefully whether the sparking is excessive or not; and if so, to what it is due.

An approach to measurement may be made by starting with a lightly loaded machine and gradually increasing the load, meanwhile shifting the rocker-arm and brushes back and forth, and noting at what load it is impossible to find a non-sparking point. In machines the brushes must be shifted to follow the armature reaction as the load increases; but one should always be able to find a place where sparking ceases, within the rated load. In fact, a machine should be able to run with 25 per cent overload before sparking is serious. If a machine begins to spark at 50 per cent of its load, it is clearly only half as useful as it might be, and this may be taken in a sense as a measure of sparking.

MANAGEMENT OF DYNAMO-ELECTRIC MACHINERY.

PART II

ELECTRICAL RESISTANCE.

Among the most important tests which it is necessary to make in connection with Dynamo-Electric Machinery are those for resistance.

There are two principal classes of resistance tests that must be made in connection with generators and motors. First, the resistance of the wires or conductors themselves, called the *metallic* resistance; and, second, the resistance of the insulation of the wires, known as the *insulation* resistance. The latter should always be as high as possible, because a low insulation resistance not only allows current to leak, but also causes "burn-outs" and other accidents. Metallic resistance, such, for example, as the resistance of the armature or field coils, is commonly tested either by the Wheatstone bridge or by the "drop" (fall-of-potential) method.

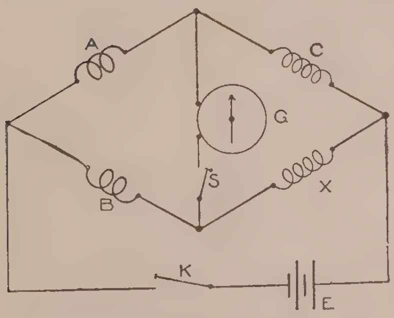

Fig. 41.

The Wheatstone Bridge is simply a number of branch circuits connected as indicated in Fig. 41. A, B, and C are resistances the values of which are known. X is the resistance which is being measured. G is a galvanometer, S its key, and E is a battery of one or two cells controlled by a key K, all being connected as shown. The resistance C is varied until the galvanometer shows no deflection, when the keys K and S are closed in the order named. If the key S should be closed before K, or at the same moment, the inductive effect would produce a pronounced deflection of the galvanometer needle, and thus probably cause confusion. The value of the resistance X is then found by multiplying together resistances C and B, and dividing by A; that is,

$$X = \frac{C \times B}{A}.$$

A very convenient form of this apparatus is what is known as the portable bridge (Fig. 42). This consists of a box containing the three sets of known resistances, A, B, and C, controlled by plugs; also the galvanometer G, and keys K and S, all connected in the proper way. In some cases further convenience is secured by including the battery E in the box; but ordinarily this is not done, and it is necessary to connect one or two cells of battery to a pair of binding-posts placed on the box for that purpose. Resistances from $\frac{1}{10}$ ohm to 100,000 ohms can be conveniently and accurately measured by the Wheatstone bridge. Below $\frac{1}{10}$ ohm the resistances of the contacts in the binding-posts and plugs are apt to cause errors, and therefore special bridges provided with mercury contact cups are used. In fact, in measuring any resistance, care should be taken to make the connections clean and tight.

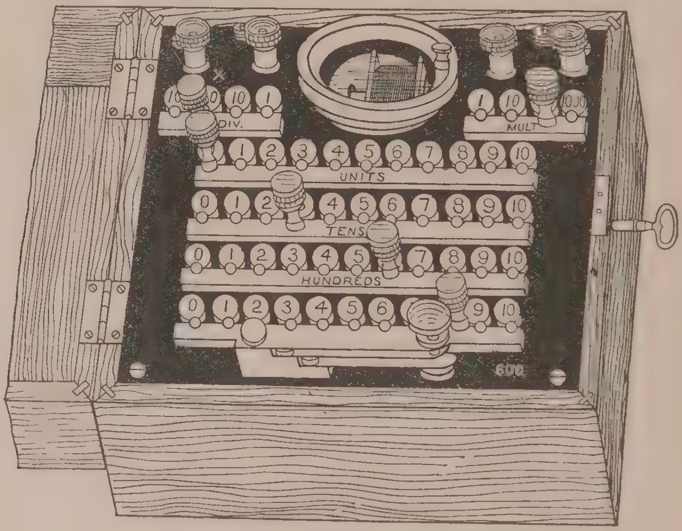

Fig. 42.

The ordinary bridge will not measure above 100,000 ohms, because, if the resistance in the arm B is 100 ohms, 1 ohm in A, and 1,000 ohms in C, then X is 100,000. Sometimes the arms A and B are provided with 1,000-ohm coils in addition to the usual 1-, 10- and 100-ohm coils; or sometimes the arm C contains more than 1,000 ohms in all; in either case the range will be correspondingly increased.

It should be observed, however, that the use of ratios of 1,000: 1, or even 100: 1, is not desirable, since they are likely to multiply any error due to contact resistances, etc. In fact, it is usually better to have the four resistances not very widely different in value; that is, no one of them should be more than ten times greater than any other except when very high or very low resistances are to be measured. The Wheatstone bridge may be used for testing the resistances of almost any field coils that are found in practice. Shunt fields for 110-volt machines usually vary from about 100 or 200 ohms in a 1-H. P. machine to about 5 to 20 ohms in a 100-H. P. machine. If the voltage is higher or lower than 110, these resistances vary as the square of the voltage. Series fields for arc-circuit dynamos vary from about 1 to 20 ohms. In measuring field resistances with the bridge, care must be taken to wait a considerable time after pressing the battery key, before pressing the galvanometer key, in order to allow time for the self-induction of the magnets to disappear.

The bridge may be used also for testing the armature resistance of some machines. But 110-volt shunt machines above 10 H. P. usually have resistances less than $\frac{1}{10}$ ohm, which is below the range of the ordinary bridge, as already stated. For higher or lower voltages the resistance is proportional to the square of the voltage. Arc machines have armatures of about 1 to 20 ohms resistance, and are therefore easily tested by the bridge.

The Drop (or **Fall-of-Potential**) **Method** is well adapted for locating faults quickly, and for testing the armature resistance of most generators and motors, or the resistance of contact between commutator and brushes, or other resistances which are usually only a few hundredths or even thousandths of an ohm. This consists in passing a current through the armature and connections and a known resistance (of, say, $\frac{1}{100}$ ohm), all connected in series, as represented in Fig. 43. The "drop" or fall of potential in the armature and that in the known resistance are compared by connecting a voltmeter first to the terminals of the known resistance (marked 1 and 2), and then to various other points on the circuit, as indicated by the dotted voltmeter terminals at M, N, O, Q, R, and S, so as to include successively each part to be tested. The deflections in all cases are directly proportional to the resistances included between the points touched by the terminals. The current needed depends upon the resistance of the circuit and the sensitiveness of the voltmeter. A bank of lamps or a liquid resistance is used for limiting the current. Instead of using a known resistance, an ammeter may be inserted in series with the resistance to be tested, the latter being then determined by Ohm's law, *viz.*, If E is the voltmeter deflection, and I represents the amperes flowing, the resistance of the part under test is $R = \frac{E}{I}$

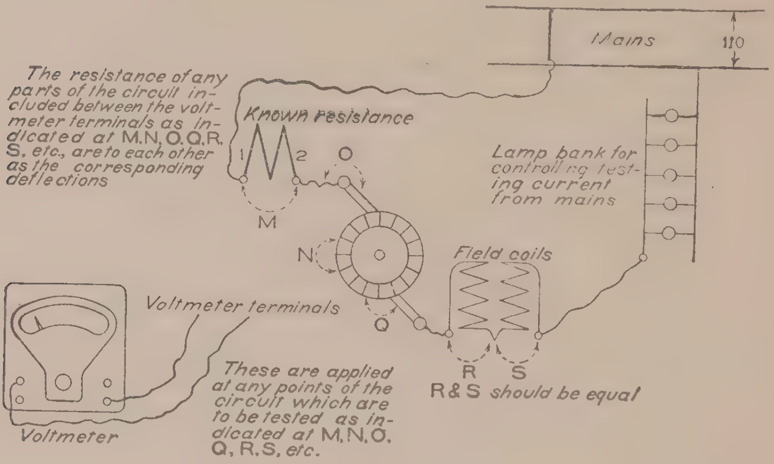
Mains
110
The resistance of any parts of the circuit included between the voltmeter terminals as indicated at M.N.O.Q.R. S, etc., are to each other as the corresponding deflections
Known resistance
1
2
O
M
N
Q
Lamp bank for controlling testing current from mains
Field coils
Voltmeter terminals
Voltmeter
These are applied at any points of the circuit which are to be tested as indicated at M.N.O. Q, R.S, etc.
R
S
R&S should be equal

Fig. 43.

A "station" or a portable voltmeter may be used for the readings, and its terminals may be held in the hands, or they may be conveniently arranged to project from an insulating handle like a two-pronged fork. Usually 10 to 100 amperes and a low-reading voltmeter are needed for low resistances.

It is well to start with a small testing current, and increase it until a good deflection is obtained on the voltmeter. If a current of several amperes cannot be had, a few cells of storage battery or some strong primary battery, such as a Bunsen, bichromate, or plunge battery, can be used with a galvanometer or low-reading voltmeter.

The diagram indicates the testing of a machine with series fields. Shunt fields must be connected directly to the line on account of their high resistance; while the armature can be connected as here shown, without being allowed to revolve.

This drop method of testing is also very useful in locating any fault. The two wires leading from the voltmeter are applied to any two points of the circuit, as indicated by the dotted lines —for instance, to two adjacent commutator segments, or to a brush tip and the commutator; any break or poor contact will be indicated immediately by the deflection being larger than at some other similar part. This shows that the fault is between the two points to which the wires are applied. Thus, by moving these along on the circuit, the exact location of any irregularity, such as a bad contact, short circuit, or extra resistance, can be found.

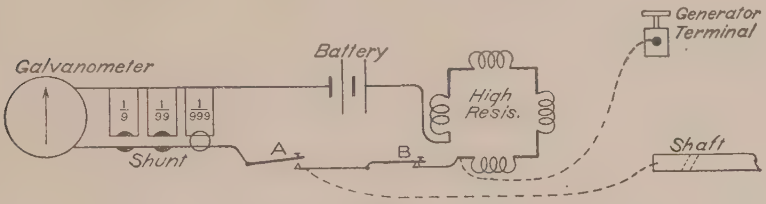

Fig. 44.

The *insulation resistance* of a generator or motor, that is, the resistance between its wires and its frame, should be sufficiently high so that not more than one-millionth of its rated current will pass through it at normal voltage, and it is well to have it still higher. It is therefore beyond the range of ordinary Wheatstone-bridge tests; but two good methods are applicable—the "direct-deflection" and the voltmeter method.

The Direct-Deflection Method is carried out by connecting a sensitive galvanometer, such as a Thomson high-resistance reflecting galvanometer, in series with a known high resistance, usually a 100,000-ohm rheostat, a battery, and keys, as shown in Fig. 44 The galvanometer should be shunted with the $\frac{1}{999}$ coil of the shunt, so that only $\frac{1}{1000}$ of the current passes through the galvanometer, the machine being entirely disconnected. The keys A and B are closed and the steady deflection noted. It is well to use but one cell of the battery at first, and then increase the number if necessary until a considerable deflection is obtained. The circuit is then opened at the key B, and connected by wires to the binding-post or commutator and to the frame or shaft of the machine, as indicated by dotted lines, so that the machine insulation resistance is included directly in the circuit with the galvanometer and battery. The key A is then closed and the deflection noted. Probably there will be little or no deflection, on account of the high insulation resistance; and the shunt is changed to $\frac{1}{99}$, $\frac{1}{9}$, or left out entirely if little deflection is obtained. In changing the shunt, the key should always be open, otherwise the full current is thrown on the galvanometer. The insulation is then calculated by the formula:

$$\text{Insulation resistance} = \frac{D \times R \times S}{d},$$

in which D is the first deflection without the machine being connected, and d the deflection with the machine insulation in the circuit, R the known high resistance, and S the ratio of the shunt. That is, if the shunt is $\frac{1}{999}$ in the first test, and $\frac{1}{9}$ in the second, then S is 100; and if the shunt is out entirely in the second test, S is 1,000. It is safer to leave the high resistance in circuit in the second test, to protect the galvanometer in case the insulation resistance is low. Therefore this resistance must be subtracted from the result to obtain the insulation of the machine itself.

By the above method it is possible to measure 100 megohms or even more. The wires and connections should be carefully arranged to avoid any possibility of contact or leakage, which would spoil the test. If no deflection is obtained, place one finger on the frame and one on the binding-post of the machine, which makes enough leakage to affect the galvanometer and show that the connections are right, thus proving that any poor insulation will be indicated if it exists.

The Voltmeter Test for Insulation Resistance requires a sensitive high-resistance voltmeter, such as the Weston. Take, for example, the 150-volt instrument, Fig. 45, which usually has about 15,000 ohms resistance. (A certificate of the exact resistance is pasted inside each case.) Apply it to some circuit or battery, and measure the voltage. This should be as high as possible—say, 100 volts. The insulation resistance of the machine is then connected into the circuit, as indicated in Fig. 46. The deflection of the voltmeter is less than before, in proportion to the value of the insulation resistance.

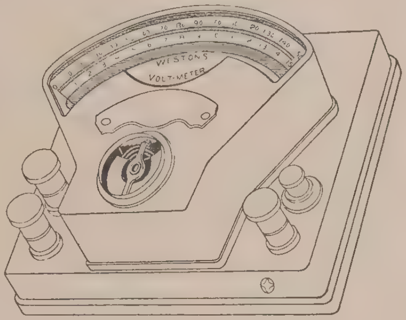

Fig. 45.

The insulation is then found by the equation:

$$\text{Insulation resistance} = \frac{D \times R}{d} - R,$$

in which D is the first and d the second deflection, and R the resistance of the voltmeter. If the circuit is 100 volts, D is 100; and if d, the deflection through the insulation resistance of the machine, is 1 division, the insulation is 1,485,000 ohms. Permanent marks indicating amounts of insulation may be put on the voltmeter scale. When making measurements, the voltage should be the same as that employed in preparing this scale (say, 115 volts). To calculate the scale use this formula:

$$d = \frac{115\ R}{X + R},$$

in which X is the insulation resistance (1 megohm, $\frac{1}{2}$ megohm, etc.), and d is the number of volts, opposite which the corresponding graduation is to be placed to form the new scale. This method does not test very high resistances; but if little or no deflection is obtained through the insulation resistance, it shows that the latter is at least several megohms—which is high enough for most practical purposes.

The ordinary magneto-electric bell may be used to test insulation by simply connecting one terminal to the binding-post of the machine, and the other to the frame or shaft.

A magneto bell is rated to ring from 10,000 to 30,000 ohms; and if it does not ring, it shows that the insulation is more than that amount. This limit is altogether too low for proper insulation in any case; and therefore this test is rough, and really shows only whether or not the insulation is very poor or the machine actually grounded.

The magneto is also used for "continuity" tests, to determine whether a circuit is complete, by simply connecting the two terminals of the magneto to those of the circuit. If the bell can be rung, it shows that the circuit is complete; if not, it indicates a break. An ordinary electric bell and cell of battery can be used in place of the magneto.

The insulation of a machine should always be tested for disruptive strength, with a current of at least double the normal working pressure, to see if it will "break down" or be punctured by the current. A transformer motor-dynamo wound to give high voltage is convenient for this.

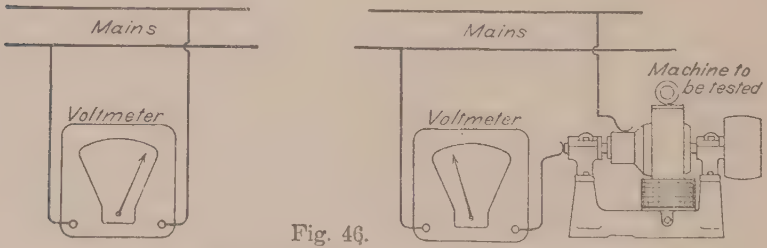

Fig. 46.

Tests of the resistances of generators or motors should properly be made when the machines are as warm as they get when running continuously at full load. This increases the resistance of conductors and decreases the insulation resistance, but it gives the actual working values.

Voltage. Instruments for measuring voltage (known as voltmeters) are in nearly all cases galvanometers of practically constant resistance. Through them flow currents which are directly proportional to the impressed voltages. A pointer connected to the moving part deflects over a graduated scale. A voltmeter should have as high a resistance as possible—at least several thousand ohms—in order not to take too much current, which might lower its reading on high-resistance circuit or consume too much power. It should not be affected by the magnetism of a generator or motor at any distance over a few feet.

The voltage of any machine or circuit is tested by merely connecting the two binding-posts or terminals of the voltmeter to the two terminals or conductors of the machine or circuit. To get the external voltage of a generator or motor, the voltmeter is usually applied to the two main binding-posts or brushes of the machine. This external voltage is what a generator supplies to the circuit. It is also called the pole difference of potential or terminal voltage, and is the actual figure upon which calculations of the efficiency, capacity, etc., of any machine are based.

A generator for constant-potential circuits should, of course, give as nearly as possible a constant voltage. A plain shunt machine usually falls from 5 to 15 per cent in voltage when its current is varied from nothing to full load. This is due to the I R drop caused by the resistance of the armature circuit, which in turn weakens the field current and magnetism; armature reaction usually occurs also, and still further lowers the external voltage, This variation is undesirable, and is usually avoided by regulating the field magnetism (varying the resistance in the field circuit) or by the use of compound-wound generators. A compound-wound dynamo should not fall appreciably from no load to full load; in fact, if it is "over-compounded" it should rise 5 per cent or more in voltage to make up for loss on the wiring.

The voltage of a constant-current generator is not important. The current should be carefully measured by an ammeter, but little attention is paid to the voltage in practical working; in fact, it changes constantly with variations in the load. But it is necessary, of course, to measure it in making efficiency or other exact tests.

A simple and fairly accurate method of measuring voltage is by means of ordinary incandescent lamps. A little practice enables one to tell whether a lamp has its proper voltage and brightness. In this way it is easy to tell if the voltage is even one or two per cent above or below the normal point. Voltages less than the ordinary can be tested by using low-voltage lamps or by estimating the brightness of high-voltage lamps. For example, a lamp begins to show a very dull red at one-third and a bright red at one-half its full voltage. Voltages higher than that of one lamp can be tested by using lamps in series. Thus 1,000 volts can be measured by using 10 lamps in series, and so on.

Current. This is measured by an ammeter (Fig. 47), which is usually cheaper than a voltmeter because it contains a comparatively small amount of wire. In testing the current of a generator or motor, it is necessary only to connect an ammeter, of the proper range, in series with the machine to be tested, so that the whole current passes through the instrument or its shunt. To test the current in the armature or the field alone, the ammeter is connected in series with the particular part. To avoid mistakes in the case of a shunt-wound generator, it is well to open the external circuit entirely in testing the current used in the field coils; for the same reason the brushes of a shunt motor should be raised before testing the current taken by the field.* In a constant-current or series-wound dynamo, the same current flows through all parts of the machine and the circuit; consequently the measurement of current is very simple.

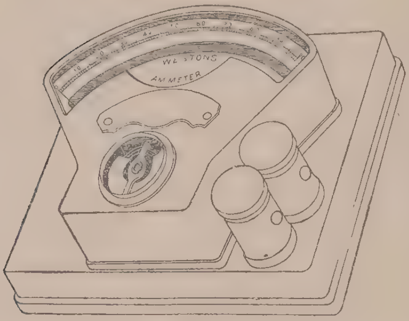

Fig. 47.

If an ammeter cannot be had, current can be measured by inserting a known resistance in the circuit and measuring the difference of potential between its ends. The volts thus indicated, divided by the resistance in ohms, gives the number of amperes flowing. If a known resistance is not at hand, the resistance of a part of the wire forming the circuit can be obtained from its diameter measured with a screw caliper or a wire gauge, by referring to any of the tables of resistances of wires; or the resistance can be measured by a Wheatstone bridge (Fig. 42), or by putting an ammeter, when one can be spared, into the circuit, while the voltmeter is connected. The volts divided by the amperes gives the resistance in ohms between the points to which the voltmeter is connected. Two connections can be attached permanently to two points on the circuit, and an ammeter temporarily inserted, and for every reading of the ammeter the corresponding reading of the voltmeter attached to these connections may be noted. Then, by keeping a list of these readings, the amperes can be found at any future time, by connecting the voltmeter to the two permanent contacts. This preliminary use of the ammeter amounts to measuring the resistance between the two contacts, and allows for the increase of resistance when the current and heating increase. In any case it is convenient to use a length of wire, or a distance between contacts, which will give an even amount of resistance, say, 1-10 or 1-100 ohm. And, as with large current the resistance will be fractional, care must be taken to avoid errors in multiplying, etc.

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* These instructions are to be followed when only one ammeter is to be had; otherwise one could be placed in the field circuit, and another in the circuit from the starting box to the independent armature terminal.

In testing the output of a generator, it is often quite a problem to dispose of the current produced. A bank of lamps, for example, to use the whole current generated by a dynamo of 110 volts and 1,000 amperes, would be very expensive. A sufficient number of resistance-boxes for the purpose would also be very costly. The best way is to drive the generator by a motor, and connect it up in parallel with the line. In this way most of the power is returned instead of being wasted. If a motor cannot be had, the simplest and cheapest way to consume a large current is to place two plates of iron in a common tub or trough filled with a weak solution of carbonate of soda (common washing soda), which is better than almost any other solution because it neither gives off fumes nor eats the electrodes. The main conductors are connected to the two plates, respectively, and the current passes through the solution. The resistance and current are regulated by varying the distance between the plates, the depth they are immersed in the liquid, and the strength of the solution. The energy may be suf-

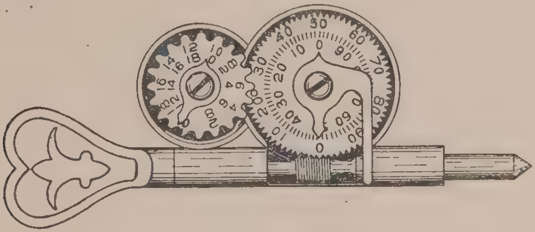

Fig. 48.

ficient to boil the liquid, but this does no harm. Three to ten amperes per square inch of active surface of plate may be allowed.

Speed. This is usually measured by the well-known **speed counter** (Fig. 48), consisting of a small spindle which turns a wheel one tooth each time it revolves. The point of the spindle is held against the center of the shaft of the generator or motor for a certain time, say, one minute or one-half minute, and the number of revolutions is read off from the position of the wheel.

Another instrument for testing the number of revolutions per minute is the **tachometer.** The stationary form of this instrument is shown in Fig. 49. It must be belted by a string, tape, or light leather belt to the machine the speed of which is to be tested. If the sizes of the pulleys are not the same, their speeds are inversely proportional to their diameters. The portable form of this instrument (Fig. 50) is applied directly to the end of the shaft of the machine, like the speed counter. The tip can be slipped upon either one of the three spindles, which are geared together, according as the speed is near 500, 1,000, or 2,000 revolutions. These instruments possess the great advantage over the speed counter that they instantly point on the dial to the proper speed, and they do not require to be timed for a certain period.

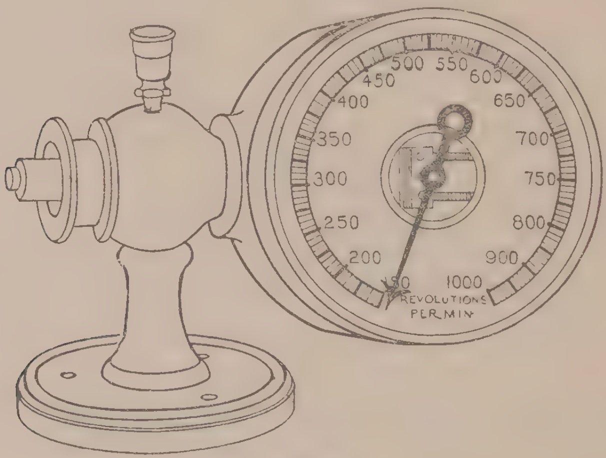

Fig. 49.

A simple way to test the speed in revolutions per minute is to make a large black or white mark on the belt of a machine, and note how many times the mark passes per minute; the length of the belt divided by the circumference of the pulley gives the number of revolutions of the pulley for each time the mark passes. The number of revolutions of the pulley to one of the belt can also be easily determined by slowly turning the pulley or pulling the belt until the latter makes one complete trip around, at the same time counting the revolutions of the pulley. If the machine has no belt, it can be supplied with one temporarily for the purpose of the test, a piece of tape with a knot or an ink mark being sufficient. Care should be taken in all these tests of speed with belts not to allow any slip; for example, in the case of the tape belt just referred to, this belt should pass around the pulley of the machine and some light wheel of wood or metal which turns so easily as not to cause any slip of the belt on the pulley of the machine.

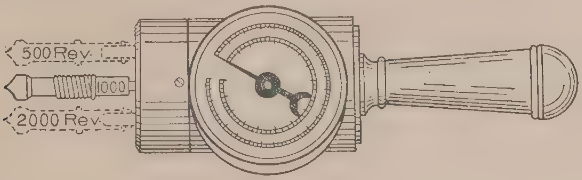

Fig. 50.

Torque or **Pull** is measured in the case of a motor by the use of a Prony brake. This consists of a lever LL of wood, clamped on the pulley of the machine to be tested, as indicated in Fig 51. The pressure of the screws SS is then adjusted by the wing-nuts until the friction of the clamp on the pulley is sufficient to cause the motor to take a given current, and the speed is then noted. Usually, the maximum torque or pull is the most important to test; and this is obtained in the case of a constant-potential motor by tightening the screws SS until the motor draws its full current as indicated by an ammeter. What the full current should be, is usually marked on the name-plate; if not, it may be assumed to be about 8 amperes per H. P. for 110-volt motors, 4 amperes per H. P. for 220-volt, and 1 3-4 amperes per H. P. for 500-volt motors. If the machine is rated in kilowatts, the full current in amperes can be found by multiplying by 1,000 and dividing by the voltage of the machine. The torque or pull is measured by known weights, or more conveniently by a spring balance P. I desired, the test may also be made at three-quarters, one-half, or any other fraction of the full current.

The torque or pull in pounds which should be obtained, can also be calculated from the power at which the machine is rated, by the formula ;

$$\text{Torque} = \frac{\text{H. P.} \times 33{,}000}{6.28 \times \text{S}},$$

in which H. P. is the horse-power of the machine at full load, and S is the speed of the machine in revolutions per minute at full load. Torque is given at unit radius, commonly pounds at one foot. The pull at any other radius is converted into torque by multiplying by the radius; 1, 2, and 4 ft. are convenient radii or lengths of lever for measuring pull. One H. P. produced at a speed of 1,000 revolutions requires a pull of 5.25 pounds at end of 1-foot lever; at 500 revolutions, twice as much; at 2,000 revolutions half as much; and so on. If the lever is 4 feet, the pull is one-fourth as much, etc.

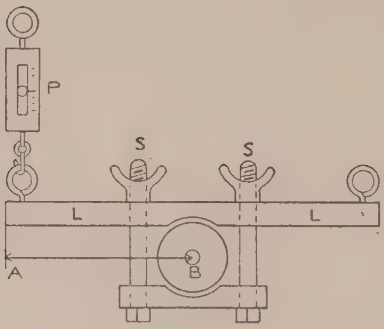

Fig. 51.

The Torque of a Generator, that is, the power required to drive it, is very conveniently determined by operating it as a motor, and testing it by the Prony brake as described above, the torque of a generator being practically equal to that of a motor under similar conditions.

Power. The electrical power of a generator or motor is found by testing the voltage and current at the terminals of the machine, as already described, and multiplying the two together, which gives the electrical power of the machine in watts.* Watts are converted into horse-power by dividing by 746, and into kilowatts by dividing by 1,000.

The mechanical power of a generator or motor, that is, the power required for or developed by it, is found by multiplying its pull by its speed and by the circumference on which the pull is measured, and dividing by 33,000. That is,

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*In testing an alternating-current machine, a wattmeter should be employed instead of a voltmeter and an ammeter, as explained later.

$$\text{Horse-power} = \frac{P \times S \times 6.28 \times R}{33{,}000},$$

in which P is the pull in pounds, S the speed in revolutions per minute, and R the radius in feet at which P is measured.

Efficiency. This is determined in the case of a generator by dividing the electrical power generated by it by the mechanical power required to drive it; that is,

$$\text{Efficiency of generator} = \frac{\text{Electrical power}}{\text{Mechanical power}}.$$

The efficiency of a motor is the mechanical power developed by it, divided by the electrical power supplied to it; that is,

$$\text{Efficiency of motor} = \frac{\text{Mechanical power}}{\text{Electrical power}}.$$

These are the **actual** or **commercial efficiencies** of these machines, and should be at least 90 per cent at rated load in machines of 10 H. P. and over.

The so-called "electrical efficiency" is misleading and of little practical importance, and should not be considered in commercial work. The mechanical and electrical power in the above equations are determined as already explained.

It is usually more convenient to test the efficiency of a generator by testing it as a motor with a Prony brake. But the efficiency of a generator may be determined very easily by driving it with a calibrated electric motor, that is, one in which the power developed for any given number of volts and amperes consumed is known. Then it is only necessary to measure the watts supplied by the generator when the motor is running at a certain power, and the efficiency of the generator is *the watts ÷ the known power.*

Another method is to employ two identical machines, one used as a motor driving the other as a generator. The shafts of the two machines should be directly connected by some form of coupling; a belt may be used, but its friction would cause a small loss. The watts produced by the generator, divided by the watts consumed by the motor, is the combined efficiency of the two machines; and the efficiency of each is the square root of that fraction. For example, if the combined efficiency is .81, then that of each machine is .90, since .90 × .90 = .81. This assumes that the two efficiencies are equal, which is sufficiently correct if the machines are exactly alike. The current from the generator may be used to help feed the motor, and then only the difference in current need be supplied. This latter current represents the inefficiency or losses from friction, etc., in both machines.

To test in this way, connect both machines in parallel with the source of current; couple or belt them together; and then weaken the field, or shift the brushes of the machine which is to be used as a motor, so that it will speed up and drive the other as a dynamo, or cause it to drive the other by putting a large pulley on it. In this way the motor will consume current from the circuit while the generator yields current to the circuit. Both currents are measured and the efficiencies calculated.

The efficiency of a motor-generator or ordinary converter is very easily determined by simply measuring the input and output in watts (by wattmeters or by ammeters and voltmeters for direct currents), and dividing the latter by the former.

These electrical methods of testing are preferable to mechanical, for the reason that the volts and amperes can be easily and accurately measured, and their product gives the power in watts.* Mechanical measurements of power by dynamometer or other means are difficult, and usually not very accurate.

Separation of Losses. The total losses in a generator or motor, except that caused by the electrical resistance of the armature when carrying the full current, can be closely determined at once by noting the current required to run the machine free as a motor. In a machine of 90 per cent efficiency, this should not amount to more than about 8 per cent of the current required to give rated power. Consequently the easiest way to test a machine is to run it as a motor without load.

The various losses of power that occur in a generator or motor may be determined and separated from each other as follows:

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* When alternating-current machinery is being tested use wattmeters

Take a generator, for example, and drive it with another machine used as a motor in the manner described for testing friction. The motor should previously be calibrated, that is, tested to determine the exact mechanical power it develops for each amount of electrical power in watts supplied to it, as described for testing efficiency. A simple, shunt-wound motor on a constant-potential circuit is best suited to the purpose. The generator is first driven at normal speed with no field magnetism and with the brushes lifted; then the actual power developed by the motor equals the power lost in the generator by the friction of bearings and belt. The brushes are then adjusted in contact with the commutator, with the usual pressure. The increase in the power of the motor is equal to the brush friction.

Finally, excite the field magnet to full strength, and the increase in the power exerted by the motor is equal to the combined losses due to the Foucault or eddy currents and hysteresis in the iron core of the armature, provided there is no considerable side pull on the armature. The power wasted in Foucault currents varies as the square of the speed, while the hysteretic loss is only directly proportional to speed; hence the two may be separated by testing the machine at different speeds.

For example, let us call x and y the losses due to hysteresis and Foucault currents, respectively, at full speed; A the power consumed by both at full speed; and B the power consumed at half speed. Then $A = x + y$, and $B = \frac{x}{2} + \frac{y}{4}$; hence, by eliminating x, we have $y = 2A - 4B$. That is the Foucault loss is twice the power consumed by both at full speed minus four times the power consumed by both at half speed. . The hysteresis loss $= A - y$. If eddy currents are developed in the copper conductors of the armature, they will increase the apparent Foucault loss as determined by the above test, since they also vary as the square of the speed. The power wasted by eddy currents might be found by testing the armature without any conductors upon it. This could be done only before the armature is wound or by unwinding it, neither of which is practicable except in the place where it is made. Ordinarily, however, eddy currents in the conductors do not amount to much unless they are very large, and even then the use of stranded conductors or conductors embedded in slots in the iron core largely overcomes the trouble.

Friction of the air might also increase the apparent Foucault loss; but it usually causes only a very small loss, and is almost impossible to separate except by running the machine in a vacuum, which is, of course, impracticable. The other losses are quite easily measured and separated, as follows :

The number of watts used in the field can be measured by a voltmeter and ammeter, or it can be calculated by the formula : $\text{Watts} = \frac{E^2}{R} = I^2R = EI$, in which E is the voltage, R the resistance, and I the current. It is sufficient if any of these two quantities are known. The loss in the armature conductors, due to ohmic resistance is found by multiplying the square of the current in the armature at full load by the armature resistance; in fact, this is usually called the " I^2R loss." This should not be more than 1 to 3 per cent in a constant-potential generator or motor, whether it be alternating-or direct-current. The sum of all the losses make up the difference between the total power consumed by the machine and the useful power that it develops.

The ordinary values of the various losses in a good generator or motor of 25 H. P. are approximately as follows :

Useful power developed	about 92	per cent.
Used in magnetizing field	about 1 to 2	"
Loss in armature resistance (I^2R)	" 1 to 2	"
Friction of bearings	about 2	"
Friction of brushes	" ½	"
Friction of air	" ½	"
Hysteresis in armature core	" 1½	"
Foucault currents in armature core	" 1½	"

Measurement of Power in A. C. Circuits. In circuits carrying alternating currents and having some inductive load either in the form of motors or arc lamps or a partly loaded transformer, etc., the ordinary method of determining the power, by voltmeter and ammeter measurements, is not applicable, as the current is seldom in phase with the E. M. F., and therefore the product *volts* × *amperes* is not the true power.

There are several means for determining the true power of an A. C. circuit, the simplest being an indicating wattmeter. A wattmeter is an electro-dynamometer provided with two coils, a fixed one of coarse wire, the other movable and of fine wire. This movable coil is connected in series with a large non-inductive resistance, so that the time-constant of the fine-wire circuit is extremely small; and hence its impedance is practically equal to its resistance; the current in, and resulting field of, the fine-wire coil will under these conditions be practically in phase with the potential difference across its terminals. The field produced by the coarse-wire coil is directly proportional to the current flowing through it at any instant. Hence, the couple acting on the fine-wire coil is proportional at a given instant to the product of these fields; so that the reading of the instrument, which depends on the mean value of the couple, will be proportional to the mean power, and, by providing the instrument with the proper scale, it can be made to read directly in watts.

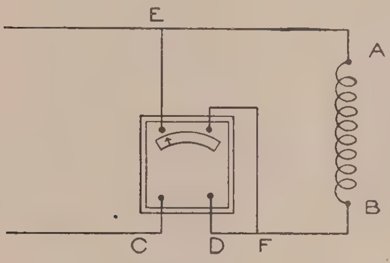

Fig. 52.

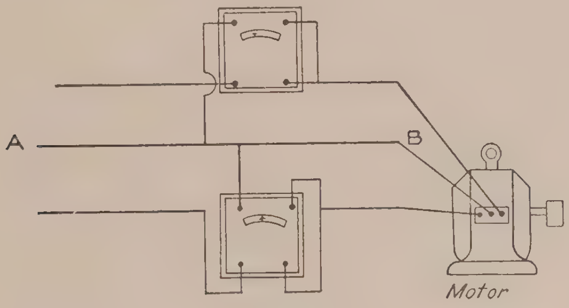

Fig. 53.

In Fig. 52, A B represents an inductive load—say, a single-phase motor—of which the power input is to be determined; C D the terminals of the thick-wire coil (current-coil) of the wattmeter; and E F the pressure-coil terminals. When connected as above indicated, the wattmeter indicates directly the power in watts supplied. In the case of a two-phase system, where the two circuits are independent, the power may be measured by placing a wattmeter in each phase, as shown in Fig. 52, and adding the two readings. If the motor be connected up as shown in Fig. 53,* where A B forms a common return, the wattmeters are placed as indicated, *care being taken to place the current-coils in the outside mains;* and the power supplied is equal to the sum of the two wattmeter readings.

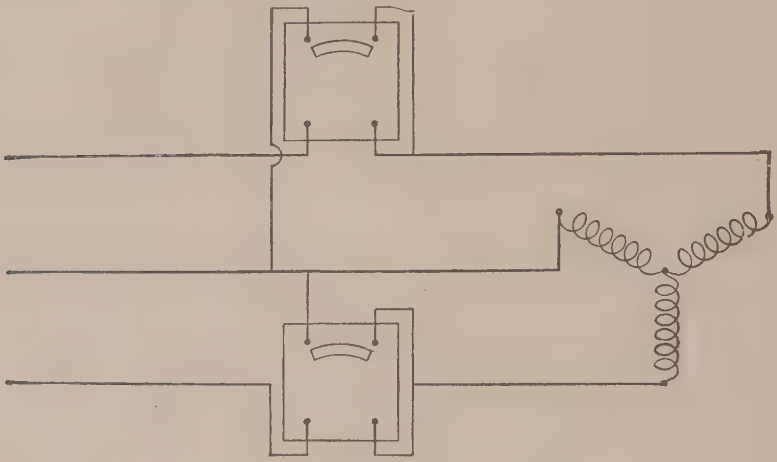

Fig. 54*a*.

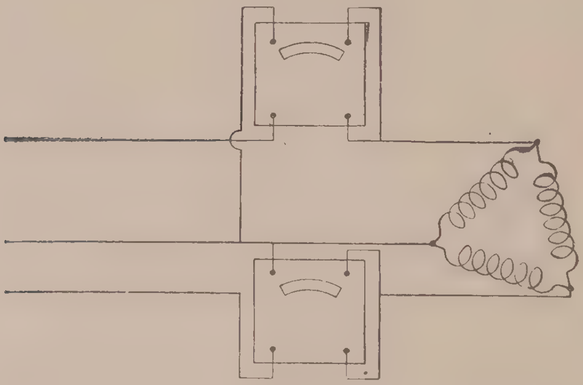

Fig. 54*b*.

The power of a balanced or unbalanced three-phase system can be determined by the use of two wattmeters connected as shown in Fig. 54, *a* and *b*. The current-carrying coils are placed in series with two of the wires, and the pressure-coil respectively connected between these two mains and the third wire. The *algebraic* sum of these two wattmeter readings gives the true power supplied. When the power factor of the system is less than .5, one of the wattmeters will read negatively It is sometimes difficult to determine whether the smaller readings are negative or not. If in doubt, give the wattmeter a separate load of incandescent lamps, and make the connections such that both instruments deflect properly; then reconnect them to the load to be measured. If the terminals of one instrument have to be reversed, the readings of that wattmeter are negative.

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* This form of connection is possible only when the generator has two independent windings, one for each phase.

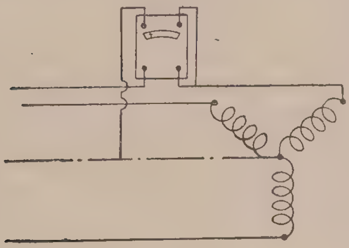

Fig. 55.

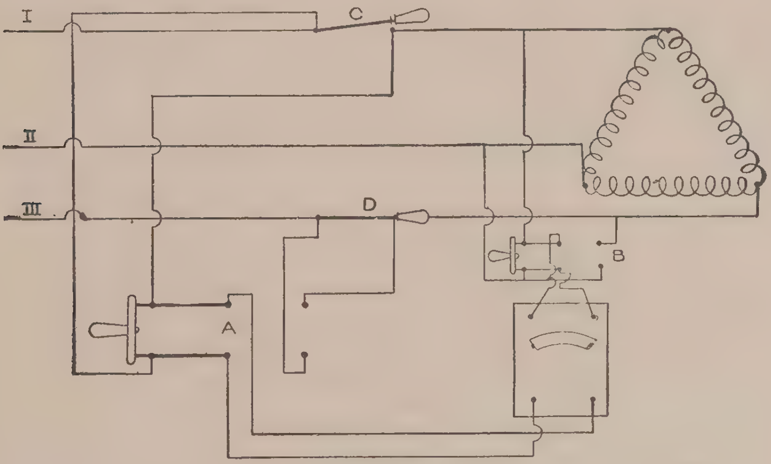

Fig. 56.

To measure the power of a balanced 4-wire 3 phase system, one wattmeter may be connected as shown in Fig. 55, and the wattmeter reading multiplied by 3. Usually, however, a 4-wire 3-phase system is unbalanced; and to determine the power supplied under this condition, three wattmeters should be employed, one for each phase, the power supplied being equal to the algebraic sum of all three readings.

It is obvious that in any of the above instances one wattmeter could be employed, provided the necessary switches are furnished. Assuming, for example, the 3-phase 3-wire case, one wattmeter would require switch connections as shown in Fig. 56. A is a double-pole switch, which, when thrown to the left, places the current-coil of the wattmeter in series with the conductor of No. I, and, when thrown to the right, places it in series with No. III. Similarly, switch B changes the pressure terminals from between I and II to III and II; while switches C and D are short-circuiting switches, one of which is closed previous to removing the current-coil from one phase to the other, and the other one opened after the coil is in position as indicated.

LOCALIZATION AND REMEDY OF TROUBLES.

The promptness and ease with which any accident or difficulty with electrical machinery can be dealt with, will always have much to do with the success of a plant. The following list of troubles, symptoms, and remedies for the various types and sizes of dynamos and motors in common use, has been prepared to facilitate the detection and elimination of such difficulties.

It is evident that the subject is somewhat complicated and difficult to handle in a general way, since so much depends upon the particular conditions in any given case, every one of which must be included in the table in such a way as to distinguish it from all others Nevertheless, it is remarkable how much can be covered by a systematic statement of the matter, and nearly all cases of trouble most likely to occur are covered by the table, so that the detection and remedy of the defect will result from a proper application of the rules given.

It frequently happens that a trifling oversight, such as allowing a wire to slip out of a binding-post, will cause as much annoyance and delay in the use of electrical machinery as the most serious accident. Other troubles, equally simple but not so easily detected, are of frequent occurrence.

The rules are made, as far as possible, self-explanatory; but a statement of the general plan followed and its most important features will facilitate the understanding and use of the table.

USE OF THE TABLE OF TROUBLES.

In the use of this table, the principal object should be to separate clearly the various causes and effects from one another. A careful and thorough examination should first be made; and, as far as possible, one should be perfectly sure of the facts, rather than attempt to guess what they are and jump at conclusions. Of course, general precautions and preventive measures should be taken before any troubles occur, if possible, rather than to wait until a difficulty has arisen. For example, one should see that the machine is not overloaded or running at too high voltage, and should make sure that the oil-cups are not empty. Neglect and carelessness with any machine are usually and deservedly followed by accidents of some sort. It is usually wise to stop the machine when any trouble manifests itself, even though it does not seem to be very serious. It is often practically impossible to shut down; but even then, spare apparatus should be ready. The continued use of defective machinery is a common but very objectionable practice.

The general plan of the table is to divide all troubles that may occur to generators or motors, into ten classes, the headings of which are the ten most important and obvious bad effects produced in these machines, *viz.:*

I. Sparking at Commutator.
II. Heating of Commutator and Brushes.
III. Heating of Armature.
IV. Heating of Field Magnets.
V. Heating of Bearings.
VI. Noisy Operation.
VII. Speed not right.
VIII. Motor stops or fails to start.
IX. Dynamo fails to generate.
X. Voltage not right.

Any one of these general effects is evident, even to the casual observer, and still more so to any person making a careful examination; hence nine-tenths of the possible cases can be eliminated immediately.

The next step is to find out which particular one of the eight or ten causes in this class is responsible for the trouble. This requires more careful examination, but nevertheless can be done with comparative ease in most cases. One cause may produce two effects, and, *vice versa*, one effect may be produced by two causes; but the table is arranged to cover this fact as far as possible. In a complicated or difficult case it is well to read through the entire table and note what causes can possibly apply. Generally there will not be more than two or three; and the particular one can be picked out by following the directions, which show how each case may be distinguished from any other.

I. SPARKING AT THE COMMUTATOR.

This is one of the most common of troubles, being often quite serious because it burns and cuts the commutator and brushes, at the same time producing heat that may spread to and injure the armature or bearings. Any machine having a commutator is liable to it, including practically all direct-current and some alternating-current machines. The latter usually have continuous collecting rings not likely to spark; but self-exciting or composite-wound alternators, rotary converters, and some alternating-current motors have supplementary direct-current commutators. A certain amount of sparking occurs normally in most constant-current dynamos for arc lighting, where it is not very objectionable, since the machines are designed to stand it and the current is small.

Cause 1. **Armature carrying too much current**, due to (*a*) overload (for example, too many lamps fed by dynamo, or too much mechanical work done by motor; a short circuit, leak, or ground on the line may also have the effect of overloading a dynamo); (*b*) excessive voltage on a constant-potential circuit, or excessive amperes on a constant-current circuit. In the case of a motor, any friction, such as armature striking pole pieces, or a shaft not turning freely, may have the same effect as overload.

Symptom. Whole armature becomes overheated, and belt (if any) becomes very tight on tension side, sometimes squeaking because of slipping on pulley. Overload due to friction is detected by stopping the machine, and then turning it slowly by hand. (See V and VI, 2.)

Remedy. (*a*) Reduce the load; or eliminate the short circuit, leak, or ground on the line; (*b*) decrease size of driving pulley, or (*c*) increase size of driven pulley; (*d*) decrease magnetic strength of field in the case of a dynamo, or increase it in the case of a motor. If excess of current cannot satisfactorily be overcome in any of the above ways, it will be necessary to change the machine or its winding. Overload due to friction is eliminated as described under V and VI, 2.

If the starting or regulating rheostat of a motor has too little resistance, it will cause the motor to start too suddenly and to spark badly at first. The only remedy is more resistance in the box.

Cause 2, **Brushes not set at the neutral point.**

Symptom. Sparking varied by shifting the brushes with rocker-arm.

Remedy. Carefully shift brushes backwards or forwards until sparking is reduced to a minimum. This can be done by simply moving the rocker-arm. If only slightly out of position, heating alone may result, without disarrangement being bad enough to show sparking. If the brushes are not exactly opposite in a bipolar, 90° apart in a four-pole machine, and so on, they should be made so, the proper points of contact being determined by counting the commutator-bars or by careful measurement.

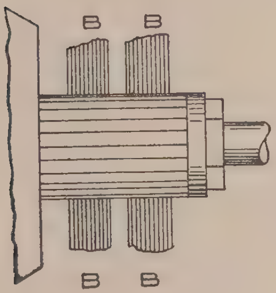

Fig. 57.

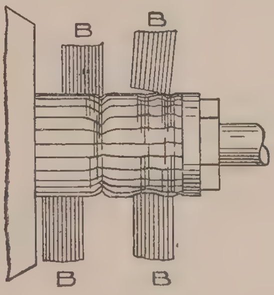

Fig. 58.

Fig. 59.

The usual position for brushes is opposite the spaces between the pole pieces, but in some machines they must be set in line with centers of pole pieces or at some other point. If the brushes are set exactly wrong, this will cause a dynamo to fail to generate and a motor to fail to start, and will blow the fuse or open the circuit-breaker. (See IX, 6.)

Cause 3. **Commutator rough, eccentric, or has one or more "high bars"** projecting beyond the others, or one or more

flat bars, commonly called **flats,** or **projecting mica,** any one of which causes the brushes to vibrate or to be actually thrown out of contact with the commutator (Figs. 58 and 59). Hard mica between the bars, which does not wear as rapidly as the copper, will prevent good contact or throw brushes off.

Symptom. Note whether there is a glaze or polish on the commutator, which shows smooth working; touch revolving commutator with tip of finger nail, and the least roughness is perceptible; or feel brushes to see if there is any jar. If the machine runs at high voltage (over 250), the commutator or brushes should be touched with a stick or quill to avoid danger of shock. In the case of an eccentric commutator, careful examination shows a rise and fall of the brush when the commutator turns slowly, or a chattering of brush when it is running fast. Sometimes, by sighting in line with brush contact, one can see daylight between commutator and brush, owing to brush jumping up and down.

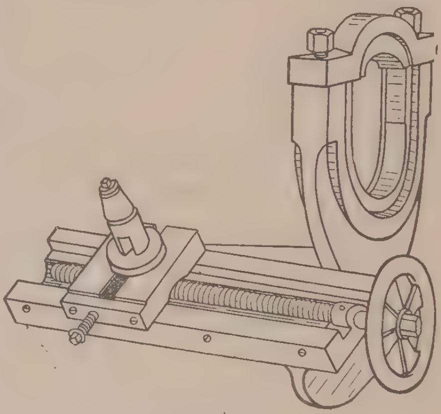

Fig. 60.

Remedy. Smooth the commutator with a fine file or fine sandpaper, which should be applied on a block of wood that exactly fits the commutator (being careful to remove any sand remaining afterward; and *never use emery*). If commutator is very rough or eccentric, the armature should be taken out and put in a lathe, and the commutator turned off. Large machines often have a slide-rest attachment (Fig. 60), so that the commutator can be turned off without removing the armature. This is clasped on the pillow-block after removing the rocker-arm.

For turning off a commutator, a diamond-pointed tool should be used, this being better than either a round or square end. It should have a very sharp and smooth edge; and only a fine cut should be taken off each time in order to avoid catching in or tearing the copper, which is very tough. The surface is then finished by applying a "dead smooth" file while the commutator revolves rapidly in the lathe. Any particles of copper should then be carefully removed from between the bars.

To have the commutator wear smooth and work well, it is desirable to have the armature shaft move freely back and forth about an eighth of an inch in the bearings while it is running. A commutator should have a glaze of a brown or bronze color. A very bright or scraped appearance does not indicate the best condition. Sometimes a very little vaseline or a drop of oil may be applied to a commutator that is rough. Too much oil is very bad, and causes the following trouble:

Cause 4. **Brushes make poor contact with commutator.**

Symptom. Close examination shows that brushes touch only at one corner, or only in front or behind, or there is dirt on surface of contact. Sometimes, owing to the presence of too much oil or from other cause, the brushes and commutator become very dirty, and covered with smut. They should then be carefully cleaned by wiping with oily rag or benzine, or by other means.

Occasionally a "glass-hard" carbon brush is met with. It is incapable of wearing to a good seat or contact, and will touch at only one or two points. Some carbon brushes are of abnormally high resistance, so that they do not make good contact. In such cases new brushes should be substituted.

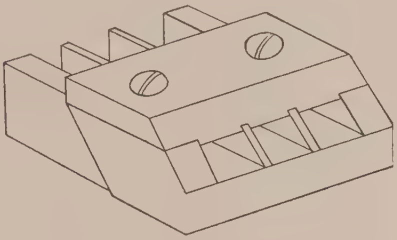

Fig. 61.

Remedy. Carefully fit, adjust, or clean brushes until they rest evenly on commutator, with considerable surface of contact and with sure but not too heavy pressure. Copper brushes require a regular brush jig (Fig. 61). Carbon brushes can be fitted perfectly by drawing a strip of sandpaper back and forth between them and the commutator while they are pressing down. A band of sandpaper may be pasted or tied around the commutator, and the armature then slowly revolved by hand or by power while the brushes are pressed upon it.

It sometimes happens that the brushes make poor contact because the brush-holders do not work freely.

Cause 5. **Short-circuited or reversed coil or coils in armature.**

Symptom. A motor will draw excessive current, even when running free without load. A dynamo will require considerable power, even without any load. For reversed coil, see III, 5.

The short-circuited coil is heated much more than the others, and is liable to be burnt out entirely; therefore the machine should be stopped immediately. If necessary to run machine in order to locate the trouble, one or two minutes is long enough; but this may be repeated until the short-circuited coil is found by feeling the armature all over.

An iron screw-driver or other tool held between the field magnets near the revolving armature, vibrates very perceptibly as the short-circuited coil passes. Almost any armature, particularly one with teeth, will cause a slight but rapid vibration of a piece of iron held near it; but a short circuit produces a much stronger effect only *once* per revolution. Care should be taken not to let the piece of iron be drawn in and jam the armature.

The current pulsates and torque is unequal at different parts of a revolution, these being particularly noticeable when several coils are short-circuited or reversed and the armature is slowly turned. If a large portion of the armature is short-circuited, the heating is distributed and is harder to locate. In this case a motor runs very slowly, giving little power but having full field magnetism. A short-circuited coil can also be detected by the drop-of-potential method. For dynamos, see IX, 3.

Remedy. A short circuit is often caused by a piece of solder or other metal getting between the commutator-bars or their connections with the armature; and sometimes the insulation between or at the ends of these bars is bridged over by a particle of metal. In any such case the trouble is easily found and corrected. If, however, the short circuit is in the coil itself, the only effective remedy is to rewind the coil.

One or more "grounds" in the armature may produce effects similar to those arising from a short circuit. (See Cause 7.)

Cause 6. **Broken circuit in armature.**

Symptom. Commutator flashes violently while running, and commutator-bar nearest the break is badly cut and burnt; but in this case no particular armature coil will be heated as in the last case; and the flashing will be very much worse, even when turning slowly. This trouble, which might be confounded with a bad case of "high bar" in commutator (Cause 3), is distinguished therefrom by slowly turning the armature, when violent flashing will continue if circuit is broken; but not with "high bar" unless it is very bad, in which case it is easily felt or seen. A very bad contact has almost the same effect as a break in the circuit.

Remedy. A break or bad contact can be located by the "drop" method (page 63) or by a continuity test (page 68). The trouble is often found where the armature wires connect with the commutator, and not in the coil itself, and the break may be repaired or the loose wire properly fastened. If the trouble is due to a broken commutator connection, and cannot be fixed, the disconnected bar may be temporarily connected to the next by solder, or the brushes may be "staggered," that is, one put a little forward and the other back so as to bridge over the break (Fig. 62). It may be impracticable to "stagger" radial and some other arrangements of brushes, but usually a brush is thick enough to make contact with more than one commutator bar. If the break is in the coil itself, rewinding is generally the only cure. But this may be remedied temporarily by connecting together by wire or solder the two commutator-bars or coil-terminals between which the break exists. It is only in an emergency that armature coils should be cut out or commutator bars connected together, or other makeshifts resorted to; but it sometimes avoids a very undesirable stoppage. A very rough but quick and simple way to connect two commutator bars, is to hammer or otherwise force the coppers together across the mica insulation at the end of the commutator. This should be avoided if possible; but if it has to be done in an emergency, the crushed material can afterwards be picked out and the injury smoothed over. In carrying out any of these methods, great care should be taken not to short-circuit any other armature coil, which would cause sparking (Cause 5).

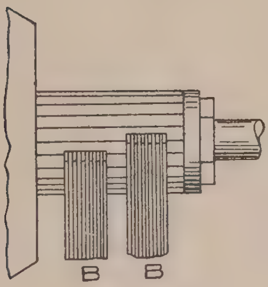

Fig. 62.

Cause 7. **Ground in Armature.**

Symptom. Two "grounds" (accidental connections between the conductors on the armature and its iron core or the shaft or spider) would have practically the same effect as a short circuit (Cause 5), and would be treated in the same way. A single ground would have little or no effect, provided the circuit is not intentionally or accidentally grounded at some other point. On an electric-railway ("trolley") or other circuit employing the earth as a return conductor, one or more grounds in the armature would allow the current to pass directly through them, and would cause the motor to spark and have a variable torque at different parts of a revolution.

Remedy. A ground can be detected by testing with a magneto bell (page 67). It can also be located by the drop-of-potential method (page 63). Another way to locate it is to wrap a wire around the commutator so as to make connection with all of the bars, and then connect a source of current to this wire and to the armature core (by pressing a wire upon the latter). The current will then flow from the armature conductors through the ground connection to the core, and the magnetic effect of the armature winding will be localized at the point where the ground is. This point is then found by the indications of a compass needle when slowly moved around the surface of the armature. The current may be obtained from a storage battery or from the circuit, but should be regulated by lamps or other resistance so as not to exceed the normal armature current. Sometimes the ground may be in a place where it can be corrected without much trouble, but usually the particular coil and often others must be rewound. A ground will be produced if the insulation is punctured by a spark of static electricity, which may be generated by the friction of the belt. If the frame of the machine is connected to the ground, the static charge will pass off to the ground; but such grounding is often inadvisable, and in such cases the frame may be connected to the ground through a Geissler tube, a wet thread, a heavy pencil-mark on a piece of unglazed porcelain, or other very high resistance which will carry off a static charge of very high potential and almost infinitesimal quantity, but will not permit the passage of any considerable current that might cause trouble.

CAUSE 8. **Weak Field Magnetism.**

SYMPTOM. Pole pieces not strongly magnetic when tested with a piece of iron. Point of least sparking is shifted considerably from normal position, owing to relatively strong distorting effect of armature magnetism. Speed of a shunt motor is usually high unless magnetism is very weak or *nil*, in which case a motor may run slow, stop, or even run backwards.* A generator fails to generate the full E.M.F. or current.

The particular cause of trouble may be found as follows: A broken circuit in the field of a motor is found by purposely opening the field circuit at some point, taking care first to disconnect armature (by putting wood under the brushes, for example), and to use only one hand, to avoid shock. If there is no spark when circuit is thus opened, there must be a broken circuit somewhere. A short circuit in the field coils is found by measuring their resistance roughly to see if it is very much less than it should be. Usually a short circuit is confined to one magnet, and will therefore weaken that one more than the others; and a piece of iron held half-way between the pole pieces will be attracted to one more than to the other. The short circuit may be found by the drop-of-potential method, by testing from the joint between the field coils to each outside terminal. "Grounding" is practically identical with short-circuiting, but one ground will not produce this effect until another occurs. A double ground, through which the current finds a complete path, is equivalent to a short circuit. In the ordinary "trolley" electric-railway system, a ground return is used, and the neutral conductor of three-wire systems is often grounded. In such cases one ground may be sufficient to cut out one or more field coils.

If one field coil is reversed and opposed to the others, it will weaken the field magnetism and cause bad sparking. This may be detected by examining the field coils to see if they are all connected in the right way, or by testing with a compass needle. (See IX, 4.) The series-coil of a compound-wound dynamo or motor is ofted connected wrongly, and will have the wrong effect, that is, will reduce the voltage of the former or raise the speed of the latter with increase of load.

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* NOTE. If the motor is not loaded, it will race.

Remedy. A broken or short circuit or a ground is easily repaired if external or accessible. If it is internal, the only remedy is to replace or rewind the faulty coil. A shunt motor will spark badly in starting if the armature is connected before the field. This can be remedied by adjusting the contacts and switch-arm. If the voltage is too low on the circuit, it may cause sparking in a shunt dynamo or motor; and if the voltage cannot be raised, the resistance of the field circuit should be reduced by unwinding a few layers of wire or by substituting other coils (See VII, VIII, IX, and X.)

Cause 9. **Vibration of Machine.**

Symptom. Considerable vibration is felt when the hand is placed upon the machine, and sparking decreases if the vibration is reduced.

Remedy. The vibration is usually due to an imperfectly balanced armature or pulley (see VI, 1), to a bad belt (see VI, 6), or to unsteady foundations; and the remedies described for these troubles should be applied.

Any considerable vibration is likely to produce sparking, of which it is a common cause. This sparking can be reduced by increasing the pressure of the brushes on the commutator, but the vibration itself should be overcome.

Cause 10. **Chatter of Brushes.**

The commutator sometimes becomes sticky when carbon brushes are used, causing friction, which throws the brushes into rapid vibration as the commutator revolves, similar to the action of a violin bow.

Symptom. Slight tingling or jarring is felt in brushes.

Remedy. Clean commutator, and oil slightly.

Cause 11. **Flying break in armature conductor.**

Symptom. No break found by test with armature standing still, but break shown by flashing at brushes when running, being usually due to centrifugal force.

Remedy. Tighten connections to commutator, or repair broken wire, etc.

EXCESSIVE HEATING IN GENERATOR OR MOTOR.

General Instructions. The degree of heat that is injurious or objectionable in a generator or motor is easily determined by feeling the various parts. If the heat is bearable to the hand, it is entirely harmless; but if unbearable, the safe limit of temperature has been approached or passed, and the heat should be reduced in some of the ways that are indicated below. In testing with the hand, allowance should be made for the fact that bare metal feels much hotter than cotton at the same temperature. The back of the hand is more sensitive than the palm for this test. If the heat has become so great as to produce an odor or smoke, the safe limit has been far exceeded, and the current should be shut off immediately and the machine stopped, as this indicates a serious trouble, such as a short-circuited coil or tight bearing. The machine should not again be started until the cause of the trouble has been found and positively overcome. Of course, neither water nor ice should ever be used to cool electrical machinery, except possibly the bearings of large machines at points where they can be applied without danger of wetting the other parts.

Feeling for heat will serve as a rough test to detect excessive temperatures or in emergencies; but, of course, the sensitiveness of the hand varies, and it makes a great difference whether the surface is a good or bad conductor of heat. The proper and reliable methods for determining rise in temperature are given on page 59, Part I.

It is very important, in all cases of heating, to locate the source of heat in the exact part in which it is produced. It is a common mistake to suppose that any part of a machine that is found to be hot is the seat of the trouble. A hot bearing may cause the armature or commutator to heat, or *vice versa.* In every case all parts of the machine should be tried to find which is the hottest, since heat generated in one part is rapidly diffused throughout the entire machine. It is better to make observations for heating by starting with the whole machine cool, which is done by letting it stand for several hours.

II. HEATING OF COMMUTATOR AND BRUSHES.

CAUSE 1. **Heat spread from another part of machine.**

SYMPTOM. Start with the machine cool, and run for a short time, so that heat will not have time to spread. The real seat of trouble is the part that heats first.

REMEDY. (See Heating of Armature, Fields, and Bearings.)

CAUSE 2. **Sparking.** Any of the causes of sparking will cause heating, which may be slight or serious.

SYMPTOM and REMEDY. See "Sparking."

CAUSE 3. **Tendency to spark, or slight sparking hardly visible.**

Sometimes before sparking appears, serious heating is produced by the causes of sparking, such as the short-circuiting of the coils as their commutator-bars pass under the brushes.

SYMPTOM. Reduced by applying the principal remedies for sparking, such as slightly shifting rocker-arm. Fine sparks may be found by sighting in exact line with the surface of contact between the commutator and brushes.

REMEDY. (See "Sparking.") Apply the remedies with extra care. This incipient sparking may be due to excessive inductance in the armature coils, which can be corrected only by reconstruction; or it may be due to insufficient field strength, and this can be cured by increasing the ampere-turns of field winding.

CAUSE 4. **Overheated commutator will decompose carbon brush.**

The effect is to cover commutator with a black film which offers resistance and aggravates the heat.

SYMPTOM. Commutator covered with dark coating; commutator, brushes and holders show marks of abnormal heat.

REMEDY. Commutator and brushes should be carefully cleaned, and the latter adjusted to make good contact at the proper points.

CAUSE 5. **Bad connections in brush-holder, cable, etc.**

SYMPTOM. Holder, cable, etc., feel hottest; unusual resistance found in these parts by "drop method."

REMEDY. Improve the connections.

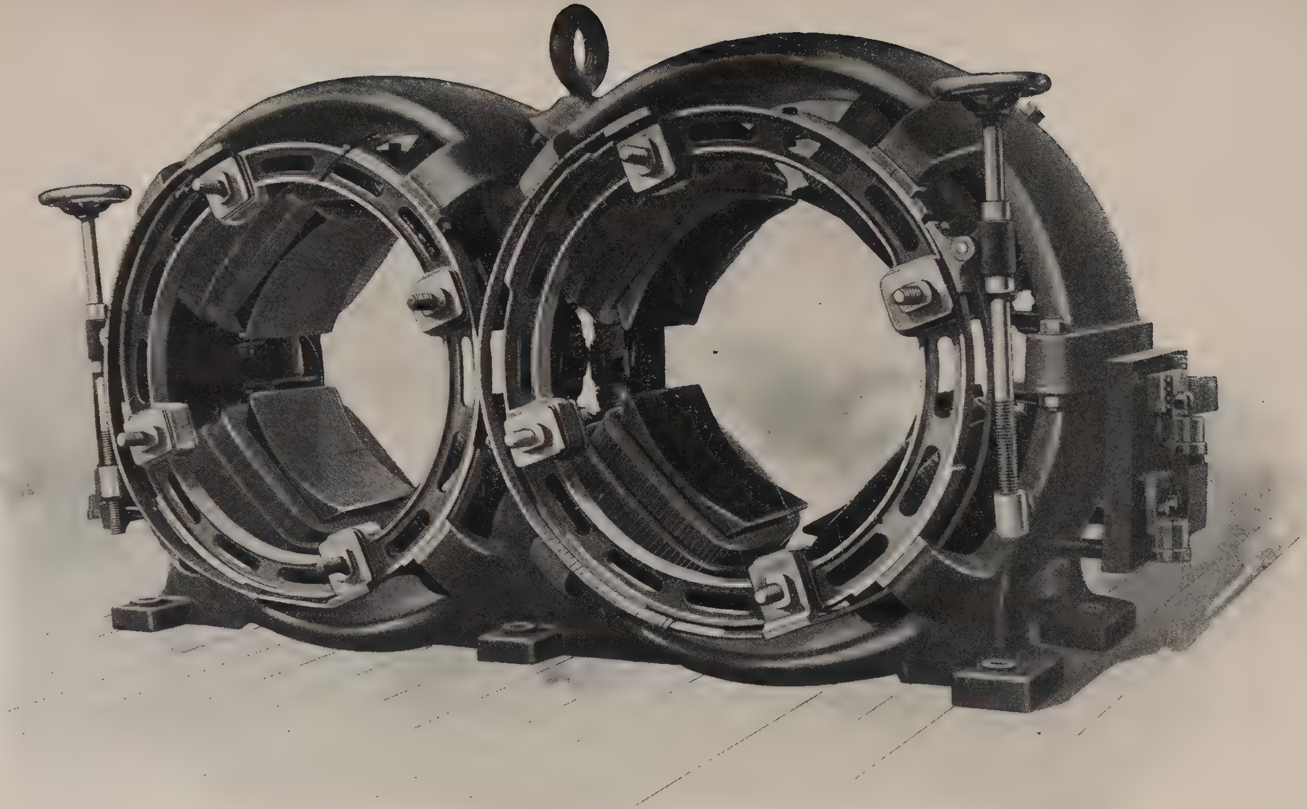
CAUSE 6. **Arcing or short circuit in commutator.**

This may occur across mica or insulation between bars or nuts.

SYMPTOM. Burnt spot between parts; spark appears in the insulation when current is put on.

REMEDY. Pick out the charred particles; take commutator apart and repair; or put on new commutator.

CAUSE 7. **Carbon brushes heated by the current.**



FIELD FRAME 200 K.W., D.C. GENERATOR.

De Laval Steam Turbine Co.

Carbon brushes require less attention than copper, because they do not cut the commutator, and their resistance usually reduces sparking, but it may also cause them to heat.

SYMPTOM. Brushes hotter than other parts.

REMEDY. Use carbon of higher conductivity. Let the brush-holder grip brush closer to commutator, so as to reduce the length of brush through which the current must pass. Reinforce the brush with copper gauze or sheet copper. Use larger brushes or a greater number.

III. HEATING OF ARMATURE.

CAUSE 1. **Excessive current in armature coils.**

SYMPTOM and REMEDY the same as in case of "Sparking," Cause 1.

CAUSE 2. **Short-circuited armature coils.**

SYMPTOM and REMEDY the same as in case of "Sparking;" Cause 5. See also Cause 7.

CAUSE 3. **Moisture in armature coils.**

SYMPTOM. Armature requires considerable power to run free. Armature steams when hot, or feels moist. This is really a special case of Cause 2, as moisture has the effect of short-circuiting the coils through the insulation. Measure insulation resistance of armature ; this should test at least one megohm if armature is in good condition, but would be much lowered by moisture. (See "Insulation Tests.")

REMEDY. The armature should be baked for 5 to 10 hours in an oven or other place sufficiently warm to drive out the moisture, but not hot enough to run any risk of burning or even slightly charring the insulation. A neat way to do this is to pass through the armature a current regulated to be about three quarters of the rated armature current, the armature being held still or turned over occasionally.

CAUSE 4. **Foucault currents in armature core.**

SYMPTOM. Iron of armature core hotter than coils after a short run, and considerable power required to run armature when

NOTE. Any excess of current taken by an armature when running *free*, whatever the cause, must be converted into heat by some defect in the motor; hence the "free current" is the simplest and most complete test of the efficiency and perfect condition of the machine.

field is magnetized and there is no load on armature. This can be distinguished from Cause 2 by absence of sparking and absence of excessive heat in a particular coil or coils after a short run. (See "Stray Power Tests.")

Remedy. Armature core should be laminated more perfectly, which is a matter of first construction.

Cause 5. **One or more reversed coils on one side of armature.** This will cause a local current to circulate around armature.

Symptom. Excessive current when running free, but no particular coil heated more than others. If a moderate current is applied to each coil in succession by touching wires carrying current to each two adjacent commutator-bars, a compass needle held over the coils will behave differently when the reversed coil is reached. In a motor the half of armature containing the reversed coils is heated more than the other.

Remedy. Reconnect the coil to agree with the others.

Cause 6. **Heat conveyed from other parts.**

Symptom. Other parts hotter than armature. Start with machine cool, and see if other parts heat first.

Remedy. See Heating of Bearings, Field and Commutator.

Cause 7. **Flying cross in armature conductor.**

Symptom and Remedy similar to the case of sparking (Cause 11), except that reference here is to the insulation of the conductors.

IV. HEATING OF FIELD MAGNETS.

Cause 1. **Excessive current in field circuit.**

Symptom. Field coils too hot to keep the hand on. Their temperature more than 50 C above that of room by resistance test or by thermometer.

Remedy. In the case of a shunt-wound machine, decrease the voltage at terminals of field coils; or increase the resistance in field circuit by winding on more wire or putting resistance in series. In the case of a series-wound machine, shunt a portion of, or otherwise decrease, the current passing through field; or take a layer or more of wire off the field coils; or rewind with coarser wire. This trouble might be due to a short circuit in field coils in the case of a shunt-wound dynamo or motor, and would be indicated by the pole piece with the short-circuited coil being weaker than the others. This coil is cooler than the others; in fact, if completely short-circuited, it is not heated at all. This condition can be remedied only by rewinding the short-circuited coil. Measure resistance of the field coils to see if they are nearly equal. (See "drop method.") If the difference is considerable (say, more than 5 or 10 per cent), it is almost a sure sign that one coil is short-circuited or double-grounded.

Cause 2. **Foucault currents in pole pieces or field cores.**

Symptom. The pole pieces hotter than the coils after a short run. When making the comparison, it is necessary to keep the hand on the coils some time before the full effect is reached, because the coils are insulated and the pole pieces are bare metal, and even then the coils will not feel so hot, although their actual temperature may be higher if measured by a thermometer.

Remedy. This trouble is due to faulty design of toothed-armature machines, which can be corrected only by rebuilding, or is caused by fluctuations in the current. The latter can be detected, if the variations are not too rapid, by putting an ammeter in circuit; or rapid variations may be felt by holding a piece of iron near the pole pieces, and noting whether it vibrates. In the case of an alternating current it is necessary to use laminated fields to avoid great heating.

Cause 3. **Moisture in field coils.**

Symptom. The field circuit tests lower in resistance than normal in that type of machine; and in the case of shunt-wound machines, the field takes more than the ordinary current. Field coils steam when hot, or feel moist to hand. The insulation resistance also tests low.

Remedy. The same as for moisture in armature (III, 3).

V. HEATING OF BEARINGS.

The cause should be found and removed promptly, but heating of the bearings can be reduced temporarily by applying cold water or ice to them. This is allowable only when absolutely necessary to keep running; and great care should be taken not to allow any water to get upon the commutator, armature, or field-coils, as it might short-circuit or ground them. If the bearing is very hot, the shaft should be kept revolving slowly, as it might "freeze," or stick fast, if stopped entirely.

CAUSE 1. **Lack of oil.**

SYMPTOM. Oil-cup reservoir empty. Oil passages clogged. Self-oiling rings stick fast. Shaft and bearing look dry. The shaft does not turn freely.

REMEDY. Supply oil, and make sure that oil passages as well as feeding or self-oiling devices work freely, and that the oil cannot leak out. This last fault sometimes causes oil to fail sooner than attendant expects. A good quality of oil should always be used, as poor oil might be as bad as no oil.

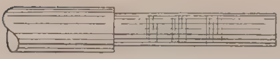


Fig. 63.

CAUSE 2. **Grit or other foreign matter in bearings.**

SYMPTOM. Best detected by removing shaft or bearing and examining both. Any grit can of course be felt easily, and will also cut the shaft.

REMEDY. Remove shaft or bearing, clean both very carefully, and see that no grit can get in. Place machine in dustless place or box it in. The oil should be perfectly clean; if not, it should be filtered. If it is not possible to stop the machine or to remove the shaft, the dirt may be washed out with kerosene or water; but these should not be allowed to get on the commutator, armature, or field coils.

CAUSE 3. **Shaft rough or cut.** (Fig. 63.)

SYMPTOM. Shaft will show grooves or roughness, and will probably revolve stiffly.

REMEDY. Turn shaft in lathe; or smooth with fine file; and see that bearing is smooth and fits shaft.

CAUSE 4. **Shaft and bearing fit too tight.**

SYMPTOM. Shaft hard to revolve by hand.

REMEDY. Turn or file down shaft in lathe, or scrape or ream out bearings.

CAUSE 5. **Shaft "sprung" or bent.**

SYMPTOM. Shaft hard to revolve, and usually sticks much more in one part of revolution than in another.

REMEDY. It is very difficult to straighten a bent shaft. It might be bent back or turned true, but probably a new shaft will be necessary.

Cause 6. **Bearings out of line.**

Symptom. Shaft hard to revolve, but is much relieved by slightly loosening the screws that hold bearings in place, when machine is not running and when belt, if any, is taken off.

Remedy. Loosen the bearings by partly unscrewing bolts or screws holding them in place, and find their easy and true position, which may require one of them to be moved either sideways or up or down; then file the screw-holes of that bearing, or raise or lower it, as may be necessary, to make it occupy the right position when the screws are tightened. The armature, however, must be kept in the center of the space between the pole pieces, so that the clearance is uniform all around. (See Cause 9.)

Cause 7. **Thrust or pressure of pulley, collar, or shoulder on shaft against one or both of the bearings.**

Symptom. Move shaft back and forth with a stick applied to the end while revolving, and note if the collar or shoulder tends to be pushed or drawn against either bearing. It is usually desirable that a shaft should move freely back and forth about an eighth of an inch, to make commutator and bearings wear smoothly.

Remedy. Line up the belt; shift collar or pulley; turn off shoulder on shaft, or file off bearing, until the shoulder does not touch when running, or until pressure is relieved.

Cause 8. **Too great a load or strain on the belt.**

Symptom. Great tension on belt. In this case the pulley bearing will probably be very much hotter than the other, and also worn elliptical, as indicated in Fig. 64, in which case the shaft can be shaken in the bearing in the direction of the belt pull, when the belt is off, provided the machine has been running long enough to wear the bearings.

Remedy. Reduce load or belt tension, or use larger pulleys and lighter belt, so as to relieve side strain on shaft. (See "Belting.")

Cause 9. **Armature too near one pole piece, producing much greater magnetic attraction on nearer side.**

Symptom. Examine the clearance of armature to see if it is uniform on all sides. Charge and discharge the field magnet, the armature being disconnected (by putting wood under the brushes);

and note whether armature seems to be drawn to one side and turns very much less easily when field is magnetized.

Remedy. This fault is due either to a defect in the original construction, or to wear in the bearings, either of which is difficult to correct; but in cases of necessity the armature can be centered exactly in the field by moving the bearings, which may be done by carefully filing the holes through which the screws pass that hold the bearings in place; or the pole piece may be filed away where it is too near the armature.

Trouble from this cause is greater in multipolar than in bipolar machines, and always tends to become aggravated, because the more the side pull the more the bearings wear in that direction. If, on the other hand, the armature is in the center of the space formed by the pole pieces, the magnetic pull is practically balanced in all directions.

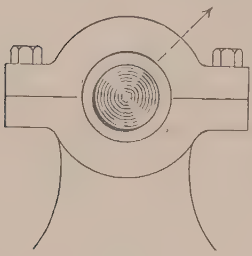


Fig. 64.

It is risky to file bolt-holes or make any such change in a machine; and this should never be attempted before consulting an experienced machinist. Very often the trouble is due to the parts being out of place merely because they have not been put together right or because there is dirt between them. If the bearing is worn, it may be rebabbitted or renewed.

Cause 10. **Bearing heated by hot pulley, commutator, or armature.**

Symptom. Pulley, armature, or commutator hotter than bearing. The slipping of the belt on the pulley, sparking at the commutator, or heating of the armature may heat one or both bearings of the machine, in which case an examination will show that these parts are hotter than the bearing, and the real source of the trouble.

Remedy. A slipping belt, sparking commutator, or hot armature can be cured as described under these headings, and then the bearing will probably cease to heat.

VI. NOISY OPERATION.

Cause 1. **Vibration due to armature or pulley being out of balance.**

Symptom. Strong vibration felt when the hand is placed upon the machine while it is running. Vibration changes greatly if speed is changed, and sometimes almost disappears at certain speeds.

Remedy. Armature or pulley must be perfectly balanced by securely attaching lead or other weight on the light side, or by drilling or filing away some of the metal on the heavy side. The easiest method of finding in which direction the armature is out of balance is to take it out, and to rest the shaft on two parallel and horizontal A-shaped metallic tracks sufficiently far apart to allow the armature to go between them (Fig. 65). If the armature is then slowly rolled back and forth, the heavy side will tend to turn downward. The armature and pulley should always be balanced separately. An excess of weight on one side of the pulley and an equal excess of weight on the opposite side of the armature will not produce a balance while running, though it does when standing still; on the contrary, it will give the shaft a strong tendency to "wobble." A perfect balance is obtained only when the weights are directly opposite, *i.e.*, in the same line perpendicular to the shaft.

Cause 2. **Armature strikes or rubs against pole pieces.**

Symptom. Easily detected by placing the ear near the pole pieces; or by examining armature to see if its surface is abraded at any point; or by examining each part of the space between armature and field as armature is slowly revolved, to see if any portion of it touches or is so close as to be likely to touch when the machine is running. In small machines, the armature may be turned by hand, noting whether it sticks at any point.

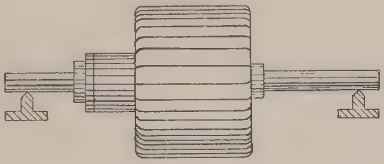


Fig. 65.

Remedy. Bind down any wire or other part of the armature that may project abnormally; or file out the pole pieces where the armature strikes; or center the armature so that there is a uniform clearance between it and the pole pieces at all points.

Cause 3. **Shaft collar or shoulder, hub or edge of pulley, or belt, strikes or scrapes against bearings.**

Symptom. Rattling noise, which stops when the shaft or pulley is pushed lengthwise away from one or the other of the bearings. (See "Heating of Bearings," Cause 7.)

Remedy. Shift the collar or pulley, turn off the shoulder on the shaft, file or turn off the bearing, move the pulley on the shaft, or straighten the belt, until there is no more striking, and the noise ceases.

Cause 4. **Rattling due to looseness of screws or other parts.**

Symptom. Close examination of the bearings, shaft, pulley, screws, nuts, binding-posts, etc., or touching the machine while running, or shaking its parts while standing still, shows that some parts are loose.

Remedy. Tighten up the loose parts, and be careful to keep them all properly set up. It is easy to guard against the occurrence of this trouble, which is very common, by simply examining the various screws and other parts each day before the machine is started. Electrical machinery being usually high-speed, the parts are particularly liable to shake loose. A worn or poorly fitted bearing might allow the shaft to rattle and make a noise, in which case the bearing should be refitted or renewed.

Cause 5. **Singing or hissing of brushes.** This is usually occasioned by rough or sticky commutator (see "Sparking," Causes 3 and 10), or by brushes not being smooth, or by the layers of a copper brush not being held together and in place. With carbon brushes, hissing will be caused by the use of carbon that is gritty or too hard. Vertical carbon brushes, or brushes inclined against the direction of rotation, are liable to squeak or sing. Occasionally, a new machine will make noise that is reduced after the machine has been run for some time.

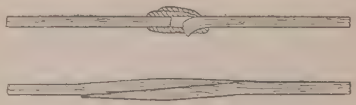


Fig. 66.

Symptom. Sound of high pitch, and easily located by placing the ear near the commutator while it is running, and by lifting off the brushes one at a time, provided there are two or more in each set, so that the circuit is not opened. If there is no current there is no objection to raising the brushes.

Remedy. Apply a *very little* oil or vaseline to the commutator with the finger or a rag. Adjust the brushes or smooth the commutator by turning or filing, or by using fine sandpaper, being careful to clean thoroughly afterwards. Carbon brushes are liable to squeak in starting up or at low speed. This decreases at full speed, and can generally be stopped by moistening the brushes with oil, care being taken not to have any drops or excess of oil. Shortening or lengthening the brushes sometimes stops the noise. Running the machine without load for some time usually reduces this trouble.

CAUSE 6. **Flapping or pounding of belt joint or lacing against pulley.** (Fig. 66.)

SYMPTOM. Sound repeated once for each complete revolution of the belt, which is much less frequent than any other generator or motor sound, and can easily be detected or counted.

REMEDY. Endless belt or smoother joint. (See "Belting.")

CAUSE 7. **Slipping of belt on pulley due to overload.**

SYMPTOM. Intermittent squeaking noise.

REMEDY. Tighten the belt or reduce the load. A wider belt or larger pulley may be required. Powdered rosin may be put on the belt to increase its adhesion; but it is a makeshift, injurious to the belt, to be adopted only if necessary. (See "Belting.")

CAUSE 8. **Humming of armature-core teeth as they pass pole-pieces.**

SYMPTOM. Pure humming sound less metallic than Cause 5.

REMEDY. Slope or chamfer the ends of the pole pieces so that each armature tooth does not pass the edge of the pole piece all at once. Decrease the magnetization of the fields. Increase the air-gap or reduce the distance between the teeth. But these are nearly all matters of first construction and are made right by good manufacturers.

CAUSE 9. **Humming due to alternating or pulsating current.**

SYMPTOM This gives a sound similar to that in the preceding case. The two can be distinguished, if necessary, by determining whether the note given out corresponds to the number of alternations, or to the number of armature teeth passing per second.

Usually the latter is considerably greater than the former.

Remedy. This trouble is confined to alternating apparatus, and its effects can be reduced by proper design and by mounting the machine so as to deaden the sound as far as possible.

It often happens that a generator or motor seems to make a noise, which in reality is caused by the engine or other machine with which it is connected. Careful listening with the ear close to the different parts will show exactly where the noise originates. A very sensitive method of locating a noise or vibration is to hold a short stick by one end between the teeth, and press the other end squarely against the several parts, to ascertain which particular one gives the greatest vibration.

VII. SPEED TOO HIGH OR TOO LOW.

This is generally a serious matter in either generator or motor, and it is always desirable and often imperative to shut down immediately, and make a careful investigation.

SPEED TOO LOW.

Cause 1. **Overload.** (See "Sparking," Cause 1.)

Symptom. Armature runs more slowly than usual. Bad sparking at commutator. Ammeter indicates excessive current. Armature heats. Belt very tight on tension side.

Remedy. Reduce the load on machine, decrease the diameter of driving pulley, or increase the diameter of driven pulley. If necessary to relieve strain of overload, temporarily decrease the voltage on either a generator or a motor.

Cause 2. **Short circuit or ground in armature.**

Symptom and Remedy the same as in case of "Heating of Armature, Cause 2 and Cause 6.

Cause 3. **Armature strikes pole pieces.**

Symptom and Remedy the same as in case of "Noise," Cause 2.

Cause 4. **Shaft does not revolve freely in the bearings.**

Symptom and Remedy the same as for "Heating of Bearings," all cases.

SPEED TOO HIGH OR TOO LOW.

Cause 5. **Field magnetism weak.**

This has the effect, on a constant-voltage circuit, of making a motor run too fast if lightly loaded, or too slow if heavily loaded, or even run backwards if the field magnet is not excited at all, as, for example, when the field circuit is broken. It makes a generator fail to "build up" or excite its field, or give the proper voltage in any case.

SYMPTOM and REMEDY the same as in case of "Sparking," Cause 8. (See the following Cause; also "Dynamo Fails to Generate ')

CAUSE 6. **Too high or too low voltage on the circuit.**

SYMPTOM. This would cause a motor to run too fast or too slow, respectively. It can be shown by measuring the voltage of the circuit.

REMEDY. The central station or generating plant should be notified that voltage is not right.

SPEED TOO HIGH.

CAUSE 7. **Motor too lightly loaded.**

SYMPTOM. A series-wound motor on a constant-potential circuit runs too fast, and may speed up to the bursting point if the load is very much reduced or removed entirely (by the breaking of the belt, for example).

REMEDY. Care should be exercised in using a series motor on a constant-potential circuit, except where the load is a fan, pump, or other machine that is *positively* connected or geared to the motor so that there is no danger of its being taken off. A shunt motor should be used if the load is likely to be thrown off.

VIII. MOTOR STOPS OR FAILS TO START.

This is an extreme case of the previous class ("Speed Too High or Too Low"), but is separated because it is more definite and permits of quicker diagnosis and treatment. This heading does not, of course, apply to generators, since any trouble in setting these in motion is usually outside of the machine itself.

CAUSE 1. **Great overload.**

A slight overload causes motor to run slowly, but an extreme overload will, of course, stop it entirely or "stall" it. (See "Sparking," Cause 1.)

SYMPTOM. On a constant-potential circuit the current is excessive, and safety-fuse blows or circuit-breaker opens. In their absence or failure, armature is burnt out.

REMEDY. Turn off switch instantly, reduce or take off the load, replace the fuse or circuit-breaker, if necessary, and turn on current again just long enough to see if trouble still exists; if so, take off more load.

CAUSE 2. **Very excessive friction due to shaft, bearings, or other parts being jammed, or armature touching pole pieces.**

SYMPTOM. Similar to previous case, but distinguished from it by the fact that the armature is hard to turn even when load is taken off. Examination shows that the shaft is too large or is bent or rough, that the bearing is too tight, that the armature touches pole pieces, or that there is some other impediment to free rotation. (See "Heating of Bearings" and "Noise.")

REMEDY. Turn current off instantly, ascertain and remove the cause of friction, turn on the current again just long enough to see if trouble still exists; if so, investigate further.

CAUSE 3. **Circuit open.**

This may be due to (*a*) safety-fuse blown or circuit-breaker open; (*b*) wire in motor broken or slipped out of connections; (*c*) brushes not in contact with commutator; (*d*) switch open; (*e*) circuit supplying motor open; (*f*) failure at generating plant.

SYMPTOM. Distinguished from causes 1 and 2 by the fact that if the load is taken off, the motor still refuses to start, and yet armature turns freely.

On a constant-potential circuit the field circuit alone of a shunt motor may be open, in which case the pole pieces are not strongly magnetic when tested with a piece of iron, and there is a dangerously heavy current in the armature; if the armature circuit is at fault, there is no spark when the brushes are lifted; and if both are without current, there is no spark when switch is opened. One should be very careful if there is no field magnetism or even if it is weak, as a motor is liable to be burnt out if the current is then thrown upon the armature.

REMEDY. Turn current off instantly. Examine safety-fuse circuit-breaker, wires, brushes, switch, and circuit generally, for break or fault. If none can be found, turn on switch again for a moment, as the trouble may have been due to a temporary stoppage of the current at the station or on the line. If motor still seems dead, test separately armature, field coils, and other parts of circuit for continuity with a magneto or a cell of battery and an electric bell, to see if there is any break in the circuit. (See "Instructions for Testing.")

One of the simplest ways to find whether the circuit has current on it and to locate any break, is to test through an incandescent lamp. Two or five lamps in series should be used on 220- and 500-volt circuits, respectively.

Cause 4. **Wrong connection or complete short circuit of field, armature, switch, etc.**

Symptom. Distinguished from Causes 1 and 2 in the same way as Cause 3, and differs from Cause 3 in the evidence of strong current in motor.

On a constant-potential circuit, if current is very great, it indicates a short circuit. If the field is at fault, it will not be strongly magnetic.

The possible complications of wrong connections are so great that no exact rules can be given. Carefully examine and make sure of the correctness of all connections (see Diagrams of Connections). This trouble is usually inexcusable, since only a competent person should ever set up a machine or change its connections.

In the 3-wire (220-volt direct-current) system, several peculiar conditions may exist, as follows:

(*a*) The dynamo or dynamos on one side of the system may become reversed, so that both of the outside wires are positive or negative. In that case a motor fed in the usual way from the two outside conductors will get no current, but lamps connected between the neutral wire and either of the outside wires will burn as usual.

(*b*) If one of the outside wires is open by the blowing of a fuse, an accidental break, or other cause, then a motor (220-volt) beyond the break can get some current at 110 volts through any lamps that may be on the same side of the break as itself, and on the same side of the system as the conductor that is open. These lamps will light up when the motor is connected, but the motor will have little or no power unless the number of lamps is large.

(*c*) If the neutral or middle wire is open, a motor connected with the outside wires will run as usual; but lamps on one side of the system will burn more brightly than those on the other side, unless the two sides are perfectly balanced.

(*d*) If one of the outside wires becomes accidentally grounded, a 110-volt dynamo, motor, or other apparatus, also grounded and connected to the other outside wire, will receive 220 volts, which will probably burn it out.

IX. DYNAMO FAILS TO GENERATE.

This trouble is almost always caused by the inability of a dynamo to "excite" or "build up" its field-magnetism sufficiently. The proper starting of a self-exciting dynamo requires a certain amount of residual magnetism, which must be increased to full strength by the current generated in the machine itself. This trouble is not likely to occur in a separately-excited machine; and if it does it is usually due to the exciter failing to generate, and therefore amounts to the same thing.

CAUSE 1. **Residual magnetism too weak or destroyed.**

This may be due to (*a*) vibration or jar; (*b*) proximity of another dynamo; (*c*) earth's magnetism; (*d*) accidental reversed current through fields, not enough to completely reverse magnetism. The complete reversal of the residual magnetism in any dynamo will not prevent its generating, but will only make it build up of opposite polarity. Sometimes reversal of residual magnetism may be very objectionable, as in case of charging storage batteries; but, although the popular supposition is to the contrary, it will not cause the machine to fail to generate.

SYMPTOM. Little or no magnetic attraction when the pole pieces are tested with a piece of iron.

REMEDY. Send a magnetizing current from another machine or battery through the field coils, then start and try the machine; if this fails, apply the current in the opposite direction, since the magnets may have enough polarity to prevent the battery building them up in the direction first tried.

Shift the brushes backward in a generator, or forward in a motor to make armature magnetism assist field. Turn machine around or change its polarity, so that the magnetism which the earth or the adjacent machine tends to induce is in the right direction. Dynamos should be placed with their opposite poles toward each other, and the north pole of a machine should preferably be placed toward the north (which is magnetically the *south* pole of the earth); but the earth's magnetism is hardly strong enough to reverse a dynamo's residual magnetism.

CAUSE 2. **Reversed connections or reverse direction of rotation.**

SYMPTOM. When running, pole pieces show no attraction for a piece of iron. The application of external current cannot be made to start the machine, as in case of Cause 1, because, whichever way the field may be magnetized, the resulting current generated by armature opposes and destroys the magnetism.

REMEDY. (*a*) Reverse either armature connections or field connections, *but not both.* (*b*) Move brushes through 180° for 2-pole, 90° for 4-pole machines, etc. (*c*) Reverse direction of rotation. After each of the above are tried, the field may have to be built up with a battery or other current, since the causes in this case operate to destroy whatever residual magnetism may have been present.

CAUSE 3. **Short circuit in the machine or external circuit.**

This applies to a shunt-wound machine, and has the effect of preventing the voltage and the field magnetism from building up.

SYMPTOM. Magnetism weak, but still quite perceptible.

REMEDY. If the short circuit is in the external circuit, opening the latter will allow the dynamo to build up and generate full voltage. If the short circuit is within the machine, it should be found by careful inspection or testing. In either of these cases, do not connect the external circuit until short circuit is found and eliminated. A slight short curcuit, such as that caused by a defective lamp socket or by copper dust on the brush-holder or commutator, may prevent the magnetism of a shunt machine from building up. (See "Sparking," Causes 5 and 8.) Too many lamps, or other load, might prevent a shunt dynamo from building up its field magnetism, in which case the load should be disconnected in starting.

CAUSE 4. **Field-coils opposed to each other.**

SYMPTOM. Upon passing a current from another dynamo of a battery the following symptom will exist: If the pole-pieces of a bipolar machine are approached with a compass or other freely suspended magnet, they both attract the same end of the magnet, showing them to be of the same polarity, whereas they should always be of opposite polarity.

For similar reasons the pole-pieces are magnetic when tested separately with a piece of iron, but show less attraction when the same piece of iron is applied to both at once, in which latter case the attraction should be stronger. In multipolar machines these tests should be applied to consecutive pole-pieces.

REMEDY. Reverse the connections of one of the coils in order to make the polarity of the pole-pieces opposite. The pole-pieces should be alternately north and south (when tested by compass).

CAUSE 5. **Open circuit.**

This may be due to (*a*) broken wire or faulty connection in machine; (*b*) brushes not in contact with commutator; (*c*) safety fuse melted or absent; (*d*) switch open; (*e*) external circuit open.

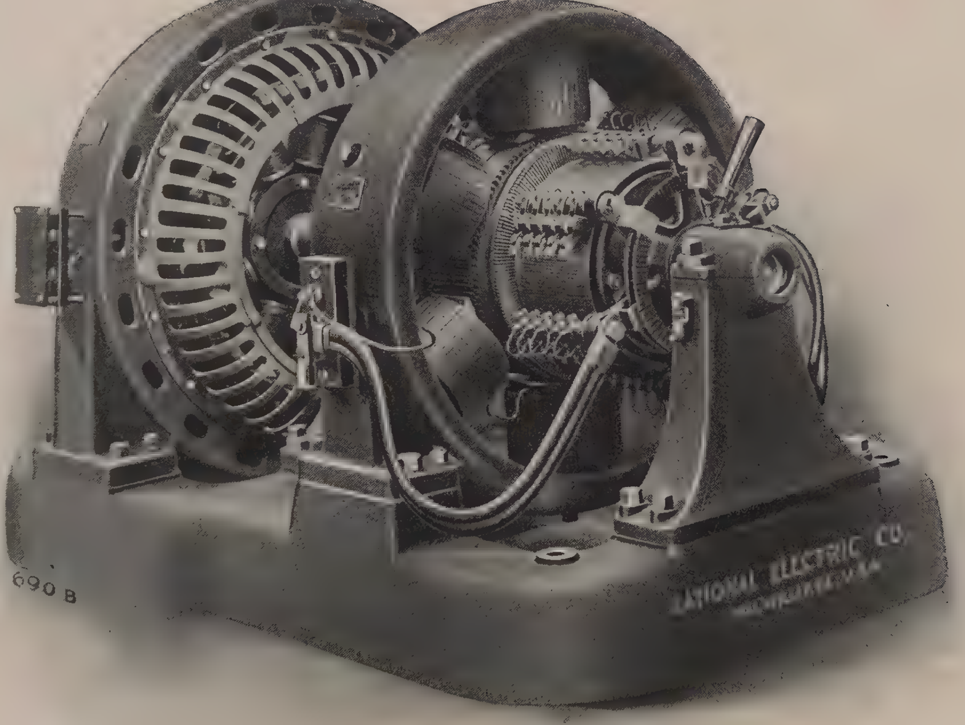
SYMPTOM. If the trouble is merely due to the switch or external circuit being open, the magnetism of a shunt dynamo may be at full strength, and the machine itself may be working perfectly; but if the trouble is in the machine, the field magnetism will probably be very weak.

REMEDY. Make very careful examination for open circuit; if not found, test separately the field-coils, armature, etc., for continuity, with magneto or cell of battery and electric bell. (See "Instructions for Testing;" also "Motor Stops," etc., Cause 3.)

A break, poor contact, or excessive resistance in the field circuit or regulator of a shunt dynamo will also make the magnetism weak and prevent its building up. This may be detected and overcome by cutting out the rheostat for a moment by connecting the two terminals of the field-coils to the two brushes respectively, care being taken not to make a short circuit.

A break or abnormally high resistance anywhere in the circuit of a series-wound dynamo will prevent it from generating, since the field-coil is in the main circuit. This may be detected and overcome by short-circuiting the machine for a moment in order to start up the magnetism.

Either of these two remedies by short-circuiting should be applied very carefully, and not until the pole-pieces have been tested with a piece of iron to make sure that the magnetism is weak.



"NATIONAL" MOTOR-EXCITER SET.

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Cause 6. **Brushes not in proper position.**

Symptom. The magnetism and current are increased by shifting the brushes.

Remedy. It often happens that the brushes are not set at the proper point; in fact, they may be set exactly wrong, so that the dynamo is incapable of generating any current whatever. This trouble is mainly due to the fact that the proper position for the brushes is not the same for all kinds of machines. Almost all ring armatures and many drum armatures require the brushes to be set opposite the *spaces* between the pole-pieces. But most armatures are wound so that the brushes must be set nearly 90° from this position, or opposite the center of the poles. Some multipolar machines have as many sets of brushes as there are pole pieces; while others have armatures that are cross-connected, or have the conductors arranged in series so that only two sets of brushes are required. Four-pole machines with only two brushes require them to be set at 90°; 6-pole machines, either 60° or 180°; 8-pole, either 45° or 135°; 10-pole, either 36°, 108°, or 180°; 12-pole, either 30°, 90°, or 150°; and 16-pole, either $22\frac{1}{2}$°, $67\frac{1}{2}$°, $112\frac{1}{2}$°, or $157\frac{1}{2}$°; and so on.

The fact is, that the proper position of the brushes depends upon the particular winding, internal connections, etc., and *no one should ever assume to know where to set the brushes* unless he is perfectly familiar with the particular type of machine. A blue print or other definite instructions should always be obtained and followed; and, if these are not available, the matter may be determined by careful trial. The proper position of brushes is the same for dynamos and motors, except that in the former the brushes are given a forward lead, that is, shifted a little in the direction of rotation, whereas motor brushes should be set a little backward. This shifting is necessitated by the armature reaction or the magnetizing effect of the armature current, which distorts the field magnetism.

The positions and number of brushes for each kind of armature are show in Fig. 67, which shows also the *arrangements of circuits* in each of the leading types.

A is the armature for the ordinary two-pole machine, and may be drum- or ring-wound. The current enters from the positive

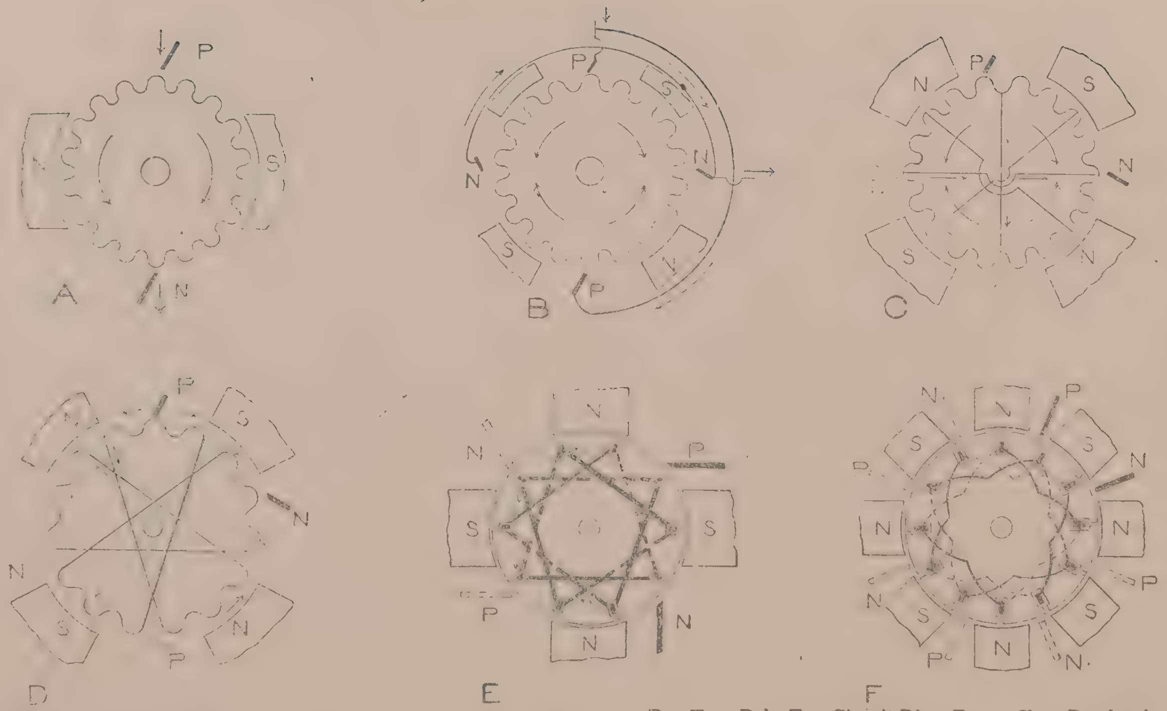


Fig. 67.

A = Two Pole, Two Circuit.
B = Four Pole, Four Circuit, Four Brushes in Multiple.
C = Four Pole, Four Circuit, Cross Connected, Two or Four Brushes in Multiple.
D = Four Pole, Two Circuit Ring, Two or Four Brushes in Multiple.
E = Four Pole, Two Circuit Drum, Two or Four Brushes in Multiple.
F = Eight Pole, Two Circuit Drum, Two, Four, Six, or Eight Brushes in Multiple.

brush, passes around both sides of the armature, and out through the negative brush. Hence this is called a "two-circuit" armature.

B is a plain armature used in a 4-pole machine. As there are here two more poles, it is necessary to use two more brushes to collect the current. This gives two brushes through which current enters, and two through which it leaves; consequently each pair of brushes must be joined in multiple in order to carry all the current to the mains.

C is a 4-pole armature in which the additional currents are carried across to the first pair of brushes by means of connections through the center of the armature. Therefore, the entire current may be taken off by these brushes; or two more may be added to divide the work, in which case they must also be connected in multiple to the first pair, as in case B above.

With either B or C, since there are two parts of the armature winding under the influence of different magnets, but running in parallel to the mains, it is evident that if the pressure of the current in one part of the winding is weaker than in the other, through inequality of the magnets or otherwise, it will short-circuit the other part of the winding and work badly.

This cannot occur in A, because both parts of the winding are influenced by the two ends of a single magnet.

D is a 4-pole armature in which the windings do not connect together in parallel but *in series*, thus overcoming the objection above. It has a ring-winding, and each coil is connected to the one diametrically opposite. An examination will show that though the poles alternate, the wire is all arranged so that the current flows in a single pair of circuits, as in A. This also permits of the use of larger wire and fewer turns, as they are connected in series instead of multiple.

E is a drum armature all in series, as in the case of D. Inspection will show that the actions of each of the four poles on all the bars harmonize, or cause the current to flow in the same direction.

To facilitate tracing the course of the current, the arrangement is represented with the smallest possible number of bars Many more are used in practice.

F is a series drum armature for eight poles. The principle is the same, but the limit of brush adjustment is smaller. The entire range from zero to full E. M. F. is covered by moving the brush one-eighth of the circumference.

As the winding is all in series, two brushes only are necessary; but as many more as desired may be added between the other poles, and then connected in multiple to the first ones. This is usually taken advantage of, because a single pair of brushes would become heated from carrying excessive current; but the difficulty of one part of the armature short-circuiting the other cannot occur, because *each part* of the winding is under the influence of all the poles.

X. VOLTAGE OF GENERATOR NOT RIGHT

VOLTAGE TOO LOW.

CAUSE 1. **Speed too low.** (See "Speed not Right.")

REMEDY. Increase speed of the prime mover, if possible; when this cannot be done, decrease the diameter of the driven pulley or increase the diameter of the driving pulley, preferably the latter.

CAUSE 2. **Field magnetism weak.**

SYMPTOM AND REMEDY. (See "Sparking," Cause 8.)

CAUSE 3. **Brushes not in proper position.**

SYMPTOM AND REMEDY. (See "Sparking," Cause 2.)

CAUSE 4. **Machine overloaded.**

SYMPTOM AND REMEDY. (See "Sparking," Cause 1 and "Speed not Right," Cause 1); also increase field excitation, if possible.

CAUSE 5. **Short-circuited armature coil or coils.**

SYMPTOM AND REMEDY. (See "Sparking," Cause 5.)

CAUSE 6. **Reversed armature coil or coils.**

SYMPTOM AND REMEDY. (See "Sparking," Cause 5.)

VOLTAGE TOO HIGH.

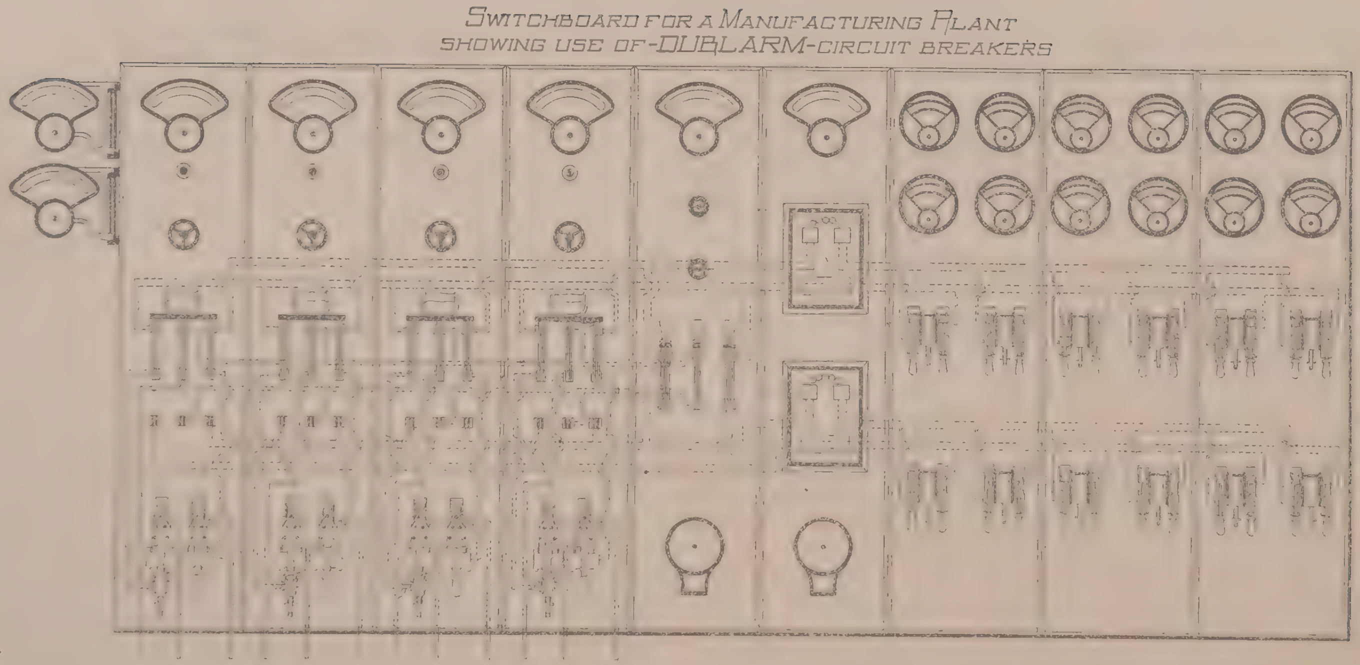
CAUSE 7. **Speed too high.**

REMEDY. Apply the reverse of treatment given in Cause 1.

CAUSE 8 **Field magnetism too powerful.**

REMEDY. Increase resistance of shunt field circuit, by means of a shunt field rheostat.

CAUSE 9. **Machine Compounds too much.**
REMEDY. Decrease resistance of series field shunt.
(See Compound-wound Dynamos, page 25, Part I.)


SWITCHBOARD FOR A MANUFACTURING PLANT
SHOWING USE OF -DUBLARM- CIRCUIT BREAKERS

SWITCHBOARD.

The Cutter Company

ELECTRIC WIRING

METHODS OF WIRING

The different methods of wiring which are now approved by the National Board of Fire Underwriters, may be classified under four general heads, as follows:

1. Wires Run Concealed in Conduits.
2. Wires Run in Moulding.
3. Concealed Knob and Tube Wiring.
4. Wires Run Exposed on Insulators.

WIRES RUN CONCEALED IN CONDUITS

Under this general head, will be included the following:

(*a*) Wires run in rigid conduits.
(*b*) Wires run in flexible metal conduits.
(*c*) Armored cable.

Wires Run in Rigid Conduit. The form of rigid metal conduit now used almost exclusively, consists of plain iron gaspipe the interior surface of which has been prepared by removing the scale and by removing the irregularities, and which is then coated with flexible enamel. The outside of the pipe is given a thin coat of enamel in some cases, and, in other cases, is galvanized. Fig. 1 shows one make of enameled (unlined) conduit.

Fig. 1. Rigid Enameled Conduit, Unlined.
Courtesy of American Conduit Mfg. Co., Pittsburg, Pa.

Another form of rigid conduit is that known as the *armored conduit*, which consists of iron pipe with an interior lining of paper impregnated with asphaltum or similar compound. This latter form of conduit is now rapidly going out of use, owing to the unlined pipe being cheaper and easier to install, and owing also to improved methods of protecting the iron pipe from corrosion, and to the introduction of additional braid on the conductors, which partly compensates for the pipe being unlined. The introduction of improved devices—such as outlet insulators, for protecting the conductors from the sharp edges of the pipe, at outlets, cut-out cabinets, etc.—also decreases the necessity of the additional protection afforded by the interior paper lining.

Rigid conduits are made in gaspipe sizes, from one-half inch to three inches in diameter. The following table gives the various data relating to rigid, enameled (unlined) conduit:

TABLE I
Rigid, Enameled Conduit—Sizes, Dimensions, Etc.

Standard Pipe Size	Thickness	Nominal Weight per 100 Feet	Number of Threads per Inch of Screw	Actual Outside Diameter. Inches	Nominal Inside Diameter. Inches
½	.109	84	14	.84	.62
¾	.113	112	14	1.05	.82
1	.134	167	11½	1.31	1.04
1¼	.140	224	11½	1.66	1.38
1½	.145	268	11½	1.90	1.61
2	.154	361	11½	2.37	2.06
2½	.204	574	8	2.87	2.46
3	.217	754	8	3.50	3.06

Tables II, III, and IV give the various sizes of conductors that may be installed in these conduits. Caution must be exercised in

TABLE II
Single Wire in Conduit

Size Wire, B. & S. G.	Loricated Conduit, Unlined; D. B. Wire
No. 14-4	½ inch
" 2	¾ "
" 1	¾ "
" 0	¾ inch or 1 "
" 00	1 "
" 000	1 "
" 0000	1 "
250,000 C. M.	1¼ "
300,000 C. M.	1¼ "
350,000 C. M.	1¼ "
400,000 C. M.	1¼ " or 1½ "
450,000 C. M.	1½ "
500,000 C. M.	1½ "
600,000 C. M.	1½ " or 2 "
700,000 C. M.	2 "
800,000 C. M.	2 "
900,000 C. M.	2 "
1,000,000 C. M.	2 " or 2½ "
1,500,000 C. M.	2½ "
1,700,000 C. M.	3 "
2,000,000 C. M.	3 "

TABLE III

Two Wires in One Conduit

Size Wire, B. & S. G.	Loricated Conduit, Unlined; D. B. Wire
No. 14	½ inch.
" 12	½ inch or ¾ "
" 10	¾ "
" 8	1 "
" 6	1 "
" 5	1 " or 1¼ "
" 4	1¼ "
" 3	1¼ "
" 2	1¼ " or 1½ "
" 1	1½ "
" 0	1½ "
" 00	1½ " or 2 "
" 000	2 "
" 0000	2 "
250,000 C. M.	2 " or 2½ "
300,000 C. M.	2½ "
350,000 C. M.	2½ "
400,000 C. M.	2½ " or 3 "
450,000 C. M.	3 "
500,000 C. M.	3 "
600,000 C. M.	3 "
700,000 C. M.	3 "

TABLE IV

Three Wires in One Conduit

Size Wire, B. & S. G.		Loricated Tube, Unlined; D. B. Wire
Outside	Center	
No. 14	No. 12	¾ inch
" 12	" 10	¾ "
" 10	" 8	1 "
" 8	" 6	1 "
" 6	" 4	1¼ "
" 5	" 2	1¼ "
" 4	" 1	1¼ inch or 1½ "
" 3	" 0	1½ "
" 2	" 2/0	1½ " or 2 "
" 1	" 3/0	2 "
" 0	" 4/0	2 "
" 2/0	250 M.	2 " or 2½ "
" 3/0	300 M.	2½ "
" 4/0	400 M.	2½ "
250 M.	450 M.	2½ " or 3 "
250 M.	500 M.	3 "
300 M.	600 M.	3 "
350 M.	700 M.	3 "
400 M.	800 M.	3 "
450 M.	900 M.	3 "

using these tables, for the reason that the sizes of conductors which may be safely installed in any run of conduit depend, of course, upon the length of and the number of bends in the run. The tables are based on average conditions where the run does not exceed 90 to 100 feet, without more than three or four bends, in the case of the smaller sizes of wires for a given size of conduit; and where the run does not exceed 40 to 50 feet, with not more than one or two bends, in the case of the larger sizes of wires, for the same sizes of conduit.

Unlined conduit can be bent without injury to the conduit, if the conduit is properly made and if proper means are used in making the bends. Care should be exercised to avoid flattening the tube as a result of making the bend over a sharp curve or angle.

In installing iron conduits, the conduits should cross sleepers or beams at right angles, so as to reduce the amount of cutting of the beams or sleepers to a minimum.

Where a number of conduits originate at a center of distribution, they should be run at right angles for a distance of two or three feet from the cut-out box, in order to obtain a symmetrical and workmanlike arrangement of the conduits, and so as to have them enter the cabinet in a neat manner. While it is usual to use red or white lead at the joints of conduits in order to make them water-tight, this is frequently unnecessary in the case of enameled conduit, as there is often sufficient enamel on the thread to make a water-tight joint.

When iron conduits are installed in ash concrete, in Keene cement, or, in general, where they are subject in any way to corrosive action, they should be coated with asphaltum or other similar protective paint to prevent such action.

While the cost of circuit work run in iron conduits is usually greater than any other method of wiring, it is the most permanent and durable, and is strongly recommended where the first cost is not the sole consideration. This method of wiring should always be used in fireproof buildings, and also in the better class of frame buildings. It is also to be recommended for exposed work where the work is liable to disturbance or mechanical damage.

Wires Run in Flexible Metal Conduit. This form of conduit, shown in Fig. 2, is described by the manufacturers as a conduit composed of "concave and convex metal strips wound spirally upon each other in such a manner as to interlock several concave surfaces and present their convex surfaces, both exterior and interior, thereby securing a smooth and comparatively frictionless surface inside and out."

The field for the use of this form of conduit is rapidly increasing. Owing to its flexibility, conduit of this type can be used in numerous cases where the rigid conduit could not possibly be employed. Its use is to be recommended above all the other forms of wiring, except that installed in rigid conduits. For new fireproof buildings, it is not so durable as the rigid conduit, because not so water-tight; and it is very difficult, if not impossible, to obtain as workmanlike a conduit system with the flexible as with the rigid type of conduit. For completed or old frame buildings, however, the use of the flexible conduit is superior to all other forms of wiring.

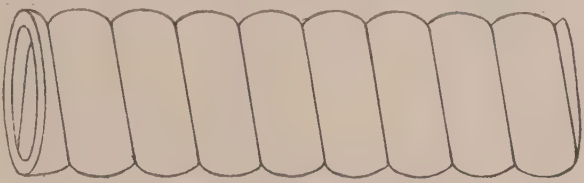


Fig. 2. Flexible Steel Conduit.
Courtesy of Sterling Electric Co., Troy, N. Y.

Table V gives the inside diameter of various sizes of flexible conduit, and the lengths of standard coils. The inside diameter of this conduit is the same as that of the rigid conduit; and the table given for the maximum sizes of conductors which may be installed in the various sizes of conduits, may be used also for flexible steel conduits, except that a little more margin should be allowed for flexible steel conduits than for the rigid conduits, as the stiffness of the latter makes it possible to pull in slightly larger sized conductors.

TABLE V

Greenfield Flexible Steel Conduit

Inside Diameter	Approximate Feet in Coil
5/16 inch	200
3/8 "	200
1/2 "	100
3/4 "	50
1 "	50
1¼ inches	50
1½ "	50
2 "	Random Lengths
2½ "	" "
3 "	" "

This conduit should, of course, be first installed without the conductors, in the same manner as the rigid conduit. Owing to the flexibility of this conduit, however, it is absolutely essential to fasten it securely at all elbows, bends, or offsets; for, if this is not done, considerable difficulty will be experienced in drawing the conductors in the conduit.

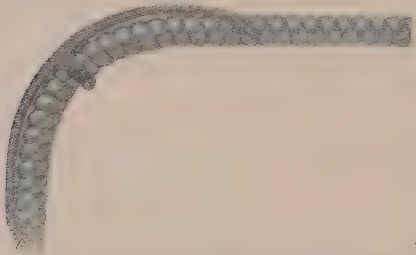


Fig. 3. Use of Elbow Clamp for Fastening Flexible Conduit in Place.

The rules governing the installation of this conduit are the same as those covering rigid conduits. Double-braided conductors are required, and the conduit should be grounded as required by the *Code Rules*. As already stated, the conduit should be securely fastened (in not less than three places) at all elbows; or else the special elbow clamp made for this purpose, shown in Fig. 3, should be used.

In order to cut flexible steel conduit properly, a fine hack saw should be employed. Outlet-boxes are required at all outlets, as well as bushing and wires to rigid conduit. Fig. 4 shows a coil of flexible steel conduit. Figs. 5, 6, and 7 show, respectively, an outlet box and cover, outlet plate, and bushing used for this conduit.

Armored Cable. There are many cases where it is impossible to install a conduit system. In such cases, probably the next best results may be obtained by the use of *steel armored cable.* The rules governing the installation of armored cable are given in the *National Electric Code,* under Section 24-A, and Section 48; also in 24–S. This cable is shown in Fig. 8.

Fig. 4. A 100-Foot Coil of Flexible Steel Conduit.
Courtesy of Sprague Electric Co., New York, N.Y.

Steel armored cable is made by winding formed steel strips over the insulated conductors. The steel strips are similar to those used for the steel conduit. Care is taken in forming the cable, to avoid crushing or abraiding the insulation on the conductors as the steel strips are fed and formed over the same. In the process of manufacture, the spools of steel ribbon are of irregular length, and when a spool is empty, the machine is stopped, and the ribbon is started on the next spool, the process being continued. There is no reason why the conduit cables could not be made of any length; but their actual lengths as made are determined by convenience in handling. Armored

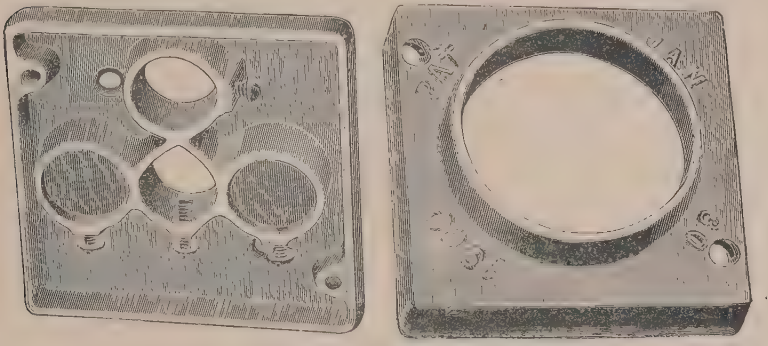


Fig. 5. Outlet Box for Flexible Steel Conduit.

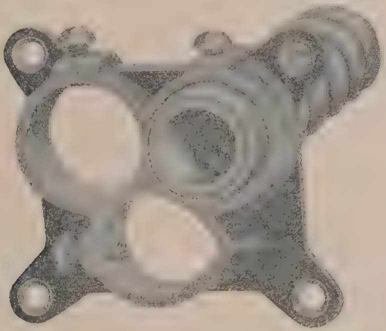


Fig. 6. Outlet Plate for Flexible Steel Conduit.

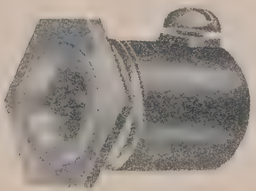


Fig. 7. Outlet Bushing.
Courtesy of Sprague Electric Co., New York, N. Y.

Fig. 8. Flexible Armored Cable. Twin Conductors.
Courtesy of Sprague Electric Co., New York, N. Y.

cable is made in *single conductors* from No. 1 to No. 10 B. & S. G.; in *twin conductors,* from No. 6 to No. 14 B. & S. G.; and *three-conductor* cable, from No. 10 to No. 14 B. & S. G. Table VI gives various data relating to armored conductors:

TABLE VI

Armored Conductors—Types, Dimensions, Etc.

SIZE B. & S. GAUGE	TYPE AND NUMBER OF CONDUCTORS	OUTSIDE DIAMETER (INCHES)
No. 14	BX twin conductor	.63
“ 12	“ “ “	.685
“ 10	“ “ “	.725
“ 8	“ “ “	.875
“ 6	“ “ “	1.3125
“ 14	BM twin conductor (for marine work—ship wiring)	.725
“ 12	“ “ “	.725
“ 10	“ “ “	.73
“ 14	BX3 three conductor	.71
“ 12	“ “ “	.725
“ 10	“ “ “	.73
“ 14	BXL twin conductor, leaded	.725
“ 12	“ “ “ “	.725
“ 10	“ “ “ “	.87
“ 14	BXL3 three conductor, leaded	.90
“ 12	“ “ “ “	.90
“ 10	“ “ “ “	.94
“ 10	Type D single conductor, stranded	.550
“ 8	“ “ “ “ “	.550
“ 6	“ “ “ “ “	.575
“ 4	“ “ “ “ “	.700
“ 2	“ “ “ “ “	.900
“ 1	“ “ “ “ “	.965
“ 10	Type DL single conductor, stranded, leaded	.625
“ 8	“ “ “ “ “ “	.710
“ 6	“ “ “ “ “ “	.700
“ 4	“ “ “ “ “ “	.760
“ 2	“ “ “ “ “ “	.920
“ 1	“ “ “ “ “ “	.910
	STEEL ARMORED FLEXIBLE CORD	
“ 18	Type E twin conductor	.40
“ 16	“ “ “ “	.40
“ 14	“ “ “ “	.47
“ 18	Type EM twin conductor, re-inforced	.575
“ 16	“ “ “ “ “	.585
“ 14	“ “ “ “ “	.595

In Table VI, Types D (single), BX (twin), and BX3 (3 conductors) are armored cable adapted for ordinary indoor work. Type BM (twin conductors) is adapted for marine wiring. Types DL (single), BXL (twin), and BXL 3 (3 conductors) have the conductors lead-encased, with the steel armor outside, and are especially adapted for damp places, such as breweries, stables, and similar places.

Type E is used for flexible-cord pendants, and is suitable for factories, mills, show windows, and other similar places. Type EM is the same as Type E; but the flexible cord is reinforced, and is suitable for marine work, for use in damp places, and in all cases where it will be subject to very rough handling.

While this form of wiring has not the advantage of the conduit system—namely, that the wires can be withdrawn and new wires inserted without disturbing the building in any way whatever—yet it has many of the advantages of the flexible steel conduit, and it has some additional advantages of its own. For example, in a building already erected, this cable can be fished between the floors and in the partition walls, where it would be impossible to install either rigid conduit or flexible steel conduit without disturbing the floors or walls to an extent that would be objectionable.

Armored conductors should be continuous from outlet to outlet, without being spliced and installed on the loop system. Outlet boxes should be installed at all outlets, although, where this is impossible, outlet plates may be used under certain conditions. Clamps should be provided at all outlets, switch-boxes, junction-boxes, etc., to hold the cable in place, and also to serve as a means of grounding the steel sheathing.

Armored cable is less expensive than the rigid conduit or the flexible steel conduit, but more expensive than cleat wiring or knob and tube wiring, and is strongly recommended in preference to the latter.

WIRES RUN IN MOULDING

Moulding is very extensively used for electric circuit work, in extending circuits in buildings which have already been wired, and also in wiring buildings which were not provided with electric circuit work at the time of their erection. The reason for the popularity of moulding is that it furnishes a convenient and fairly good-looking runway for the wires, and protects them from mechanical injury.

It seems almost unwise to place conductors carrying electric current, in wood casing; but this method is still permitted by the *National Electric Code,* although it is not allowed in damp places or in places where there is liability to dampness, such as on brick walls, in cellars, etc.

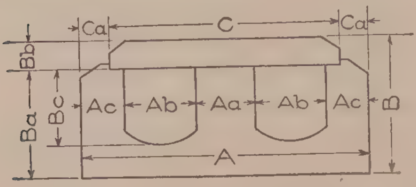


Fig. 9. Two-Wire Wood Moulding.

The dangers from the use of moulding are that if the wood becomes soaked with water, there will be a liability to leakage of current between the conductors run in the grooves of the moulding, and to fire being thereby started, which may not be immediately discovered. Furthermore, if the conductors are overloaded, and consequently overheated, the wood is likely to become charred and finally ignited. Moreover, the moulding itself is always a temptation as affording a good "round strip" in which to drive nails, hooks, etc. However, the convenience and popularity of moulding cannot be denied; and until some better substitute is found, or until its use is forbidden by the *Rules,* it will continue to be used to a very great extent for running circuits outside of the walls and on the ceilings of existing buildings. Figs. 9, 10, 11, and 12 show two- and three-wire moulding respectively; and Table VII gives complete data as to sizes of the moulding required for various sizes of conductors.

While the *Rules* recommend the use of hardwood moulding, as a matter of fact probably 90 per cent of the moulding used is of whitewood or other similar cheap, soft wood. Georgia pine or oak ordinarily costs about twice as much as the soft wood. In designing moulding work, if appearance is of importance, the moulding circuits should be laid out so as to afford a symmetrical and complete design. For

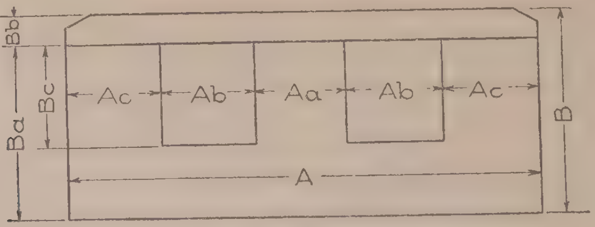
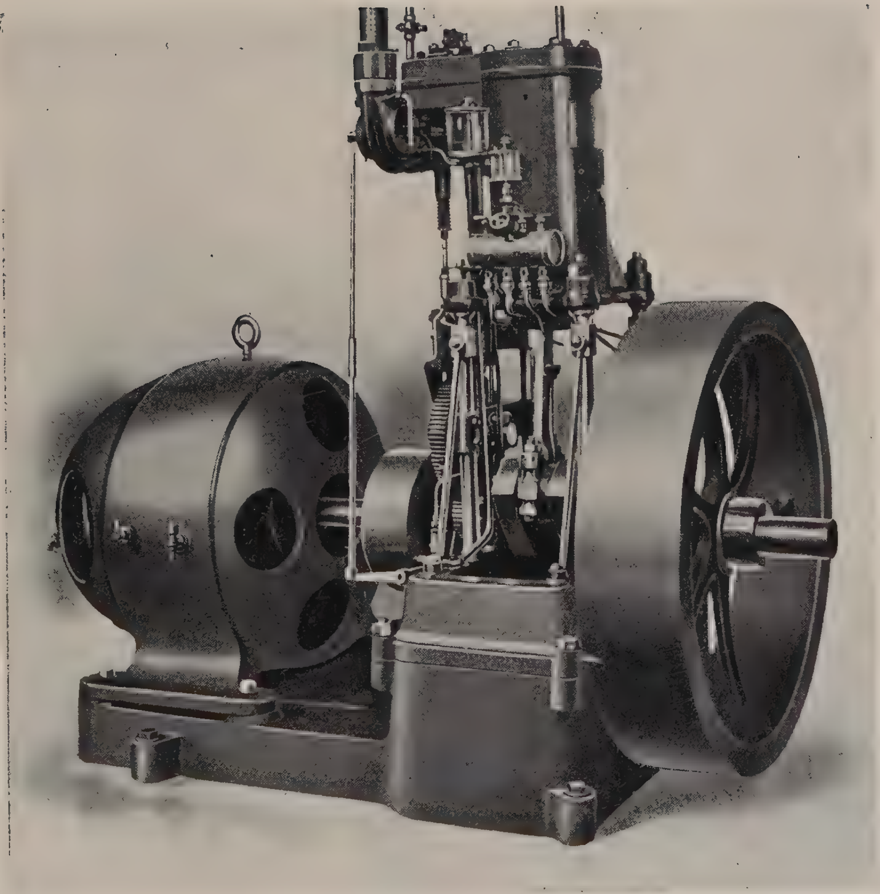


Fig. 10. Two-Wire Wood Moulding.



5 KILOWATT, 80 LIGHT.

Secor Oil-Electric Generating Plant.

example, if an outlet is to be located in the center of the ceiling, the moulding should be continued from wall to wall, the portion beyond the outlet, of course, having no conductors inside of the moulding. If four outlets are to be placed on the ceiling, the rectangle of moulding should be completed on the fourth side, although, of course, no conductors need be placed in this portion of the moulding. Doing this increases the cost but little and adds greatly to the appearance.

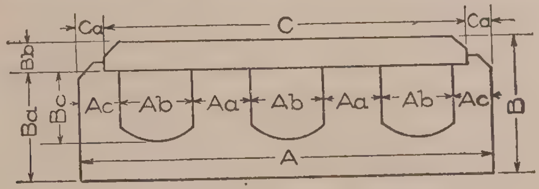


Fig. 11. Three-Wire Wood Moulding.

Moulding is frequently used in combination with other methods of wiring, including armored cable, flexible steel tubing, and fibrous tubing. In many instances, it is possible to fish tubing between beams or studs running in a certain direction; but when the conductors are to run in another direction or at right angles to the beams or studs, exposed work is necessary. In such cases, a junction-box or outlet-box must be placed at the point of connection between the moulding and the armored cable or steel tubing.

Where circuits are run in moulding, and pass through the floor, additional protection must be provided, as required by the *Code Rules*, to protect the moulding. As a rule, it is better to use conduit for all portions of moulding within six feet of the floor, so as to avoid the possibility of injury to the circuits. Where a combination of iron conduit or flexible steel tubing is used with moulding, it is well to use double-braided conductors throughout, because, although only single-

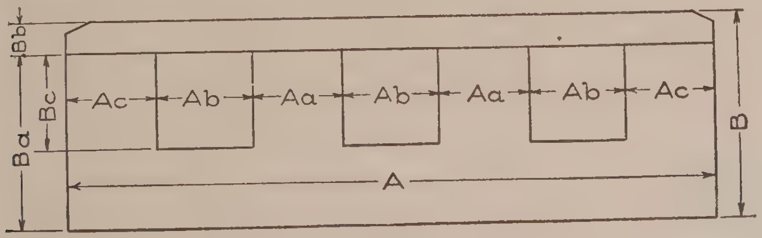


Fig. 12. Three-Wire Wood Moulding.

TABLE VII

Sizes of Mouldings Required for Various Sizes of Conductors

FIG. No.	TYPE OF MOULDING	NUMBER OF WIRES	MAXIMUM SIZE OF WIRE B AND S. GAUGE		DIMENSIONS IN INCHES									
			SOLID	STRANDED	A	Aa	Ab	Ac	B	Ba	Bb	Bc	C	Ca
9	A-2	2	12	14	1 1/2	1/2	1/4	1/4	27/32	5/8	7/32	1/4	1 1/8	3/16
9	A-4	2	8	10	1 11/16	1/2	5/16	9/32	29/32	11/16	7/32	5/16	1 5/16	3/16
9	A-6	2	4	5	2	1/2	7/16	5/16	1 1/16	13/16	1/4	7/16	1 9/16	7/32
9	A-8	2	1	2	2 3/8	1/2	9/16	3/8	1 3/16	15/16	1/4	9/16	1 13/16	9/32
9	A-9	2	—	3/0	3	5/8	3/4	7/16	1 13/32	1 1/8	9/32	3/4	2 7/16	9/32
10	A-10	2	—	250,000 C.M.	3 15/16	11/16	7/8	3/4	1 11/16	1 3/8	5/16	7/8	—	—
10	A-11	2	—	400,000 C.M.	4 7/8	15/16	1	31/32	2 3/16	1 7/8	5/16	1	—	—
11	B-2	3	12	14	2 3/16	7/16	1/4	9/32	27/32	5/8	7/32	1/4	1 13/16	3/16
11	B-4	3	8	10	2 1/2	15/32	5/16	5/16	29/32	11/16	7/32	5/16	2 1/8	3/16
11	B-6	3	4	5	2 7/8	13/32	7/16	3/8	1 1/16	13/16	1/4	7/16	2 3/8	1/4
11	B-8	3	1	2	3 5/8	19/32	9/16	3/8	1 3/16	15/16	1/4	9/16	3 1/16	9/32
11	B-9	3	—	3/0	4 5/16	9/16	3/4	15/32	1 13/32	1 1/8	9/32	3/4	3 3/4	9/32
12	B-10	3	—	250,000 C.M.	5 1/2	23/32	7/8	23/32	1 11/16	1 3/8	5/16	7/8	—	—
12	B-11	3	—	400,000 C.M.	6 3/4	15/16	1	15/16	2 3/16	1 7/8	5/16	1	—	—

braided conductors are required with moulding, double-braided conductors are required with unlined conduit, and if double-braided conductors were not used throughout, it would be necessary to make a joint at the outlet-box where the moulding stopped and the conduit work commenced. Where the conductors pass through floors, in moulding work, and where iron conduit is used, the inspection authorities, in order to protect the wire, usually require that a fibrous tubing be used as additional protection for the conductors inside of the iron pipe, although, if double-braided wire is used, this will not usually be required. Fig. 13 shows a fuseless cord rosette for use with moulding work. Fig. 14 shows a device for making a *tap* in moulding wiring.

Moulding work, under ordinary conditions, costs about one-half as much as circuit run in rigid conduit, and about 75 per cent, under ordinary conditions, of the cost of armored cable. Where the latter method of wiring or the conduit system can be employed, one or the other of these two methods should be used in preference to moulding,

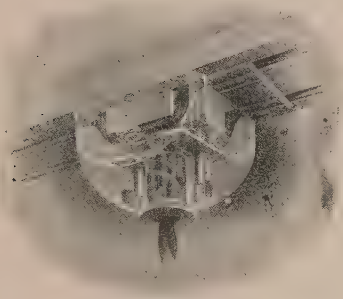


Fig. 13 Fuseless Cord Rosette.
Courtesy of Crouse-Hinds Co., Syracuse, N. Y.

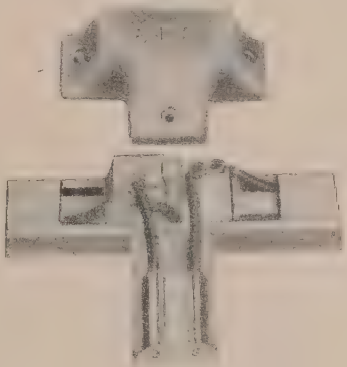


Fig. 14. Device for Making "Tap" in Moulding.
Courtesy of H. T. Paiste Co., Philadelphia, Pa.

as the work is not only more substantial, but also safer. Various forms of metal moulding have been introduced, but up to the present time have not met with the success which they deserve.

CONCEALED KNOB AND TUBE WIRING

This method of wiring is still allowed by the *National Electric Code,* although many vigorous attempts have been made to have it abolished. Each of these attempts has met with the strongest opposition from contractors and central stations, particularly in small towns and villages, the argument for this method being, that it is the cheapest method of wiring, and that if it were forbidden, many places which are wired according to this method would not be wired at all, and the use of electricity would therefore be much restricted, if not entirely done away with, in such communities. This argument, however, is only a temporary makeshift obstruction in the way of inevitable progress, and in a few years, undoubtedly, the concealed knob and tube method will be forbidden by the *National Electric Code.*

The cost of wiring according to this method is about one-third of the cost of circuits run in rigid conduit, and about one-half of the cost of circuits run in armored cable. The latter method of wiring is rapidly replacing knob and tube wiring, and justly so, wherever the additional price for the latter method of wiring can be obtained. As the name indicates, this method of wiring employs *porcelain knobs* *and tubes*, the circuit work being run *concealed* between the floor beams and studs of a frame building. The knobs are used when the circuits run parallel to the floor beams; and the porcelain tubes are used when the circuits are run at right angles to the floor beams.

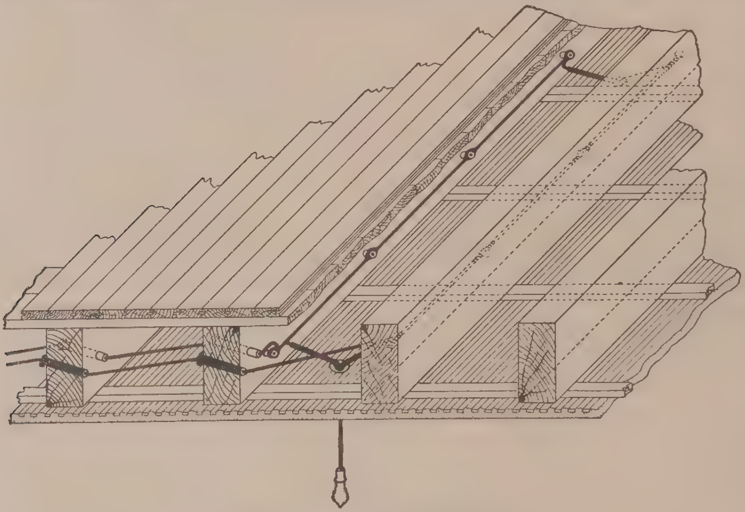


Fig. 15. Knob and Tube Wiring.

Fig. 15 shows an example of knob and tube wiring. In concealed knob and tube wiring, the wires must be separated at least ten inches from one another, and at least one inch from the surface wired over, that is, from the beams, flooring, etc., to which the insulator is fastened. Fig. 16 shows a good type of porcelain knob for this class of wiring. For knob and tube wiring, it will be noted that, owing to the fact that the wiring is concealed, the conductors must be kept further apart than in the case of exposed or open wiring on insulators, where, except in damp places, the wires may be run on cleats or on insulators only one-half inch from the surface wired over.

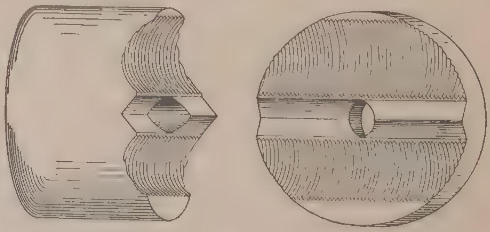


Fig. 16. Porcelain Knob.

Fibrous Tubing. Fibrous tubing is frequently used with knob and tube wiring, and the regulations governing its use are given in Rule 24, Section S, of the *National Electric Code*. This tubing, as stated in this *Rule,* may be used where it is impossible and impracticable to employ knobs and tubes, provided the difference in potential between the wires is not over 300 volts, and if the wires are not subject to moisture. The cost of wiring in flexible fibrous tubing is approximately about the same as the cost of knob and tube wiring. Duplex conductors, or two wires together are not allowed in fibrous tubing.

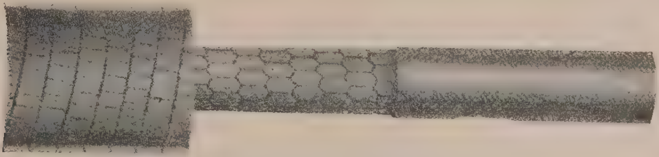


Fig. 17. Flexible Tubing, "Flexduct" Type.
Courtesy of National Metal Molding Co., Pittsburg, Pa.

Fibrous tubing is required at all outlets where conduit or armored cable is not used (as in knob and tube wiring); and, as required by the *Rules,* it must extend back from the last porcelain support to one inch beyond the outlet. Fig. 17 shows one make of fibrous tubing.

Table VIII gives the maximum sizes of conductors (double-braided) which may be installed in fibrous conduit.

TABLE VIII

Sizes of Conductors in Fibrous Conduit

OUTSIDE DIAMETER	INSIDE DIAMETER	ONE WIRE IN TUBE
$\frac{17}{32}$ inch	$\frac{1}{4}$ inch	No. 12
$\frac{21}{32}$ "	$\frac{3}{8}$ "	" 8
$\frac{25}{32}$ "	$\frac{1}{2}$ "	" 6
$\frac{15}{16}$ "	$\frac{5}{8}$ "	" 1
$1\frac{3}{32}$ "	$\frac{3}{4}$ "	" 2/0
$1\frac{5}{16}$ "	1 "	250,000 C. M.
$1\frac{9}{16}$ "	$1\frac{1}{4}$ "	400,000 C. M.
$1\frac{13}{16}$ "	$1\frac{1}{2}$ "	750,000 C. M.
$2\frac{1}{8}$ "	$1\frac{3}{4}$ "	1,000,000 C. M.
$2\frac{3}{8}$ "	2 "	1,500,000 C. M.
$2\frac{5}{8}$ "	$2\frac{1}{4}$ "	2,000,000 C. M.

WIRES RUN EXPOSED ON INSULATORS

This method of wiring has the advantages of cheapness, durability, and accessibility.

Cheapness. The relative cost of this method of wiring as compared with that of the concealed conduit system, is about fifty per cent of the latter if rubber-covered conductors are used, and about forty per cent of the latter if weatherproof slow-burning conductors are used. As the *Rules* of the Fire Underwriters allow the use of weatherproof slow-burning conductors in dry places, considerable saving may be effected by this method of wiring, provided there is no objection to it from the standpoint of appearance, and also provided that it is not liable to mechanical injury or disarrangement.

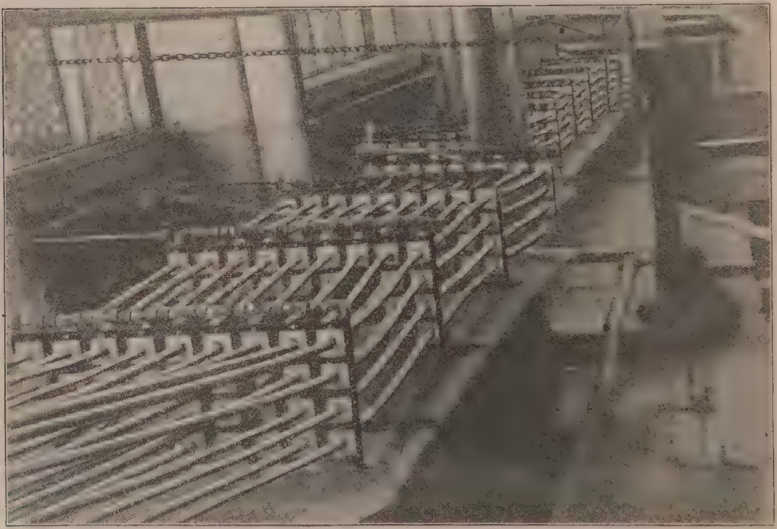


Fig. 18. Large Feeders Run Exposed on Insulators.

Durability. It is a well-known fact that rubber insulation has a relatively short life. Inasmuch as in this method of wiring, the insulation does not depend upon the insulation of the conductors, but on the insulators themselves, which are of glass or porcelain, this system is much more desirable than any of the other methods. Of course, if the conductors are mechanically injured, or the insulators broken, the insulation of the system is reduced; but there is no gradual deterioration as there is in the case of other methods of wiring, where rubber is depended upon for insulation. This is especially true in hot places, particularly where the temperature is 120° F. or above. For such cases, the weatherproof slow-burning conductors on porcelain or glass insulators are especially recommended.

Accessibility. The conductors being run exposed, they may be readily repaired or removed, or connections may be made to the same. This method of wiring is especially recommended for mills, factories, and for large or long feeder conductors. Fig. 18 shows examples of exposed large feeder conductors, installed in the New York Life Insurance Building, New York City. For small conductors, up to say No. 6 B. & S. Gauge each, porcelain cleats may be used to support one, two, or three conductors, provided the distance between the conductors is at least 2½ inches in a two-wire system, and 2½ inches between the two outside conductors in a three-wire system where the potential between the outside conductors is not over 300 volts. The cleat must hold the wire at least one-half inch from the surface to which the cleat is fastened; and in damp places the wire must be held at least one inch from the surface wired over. For larger conductors,

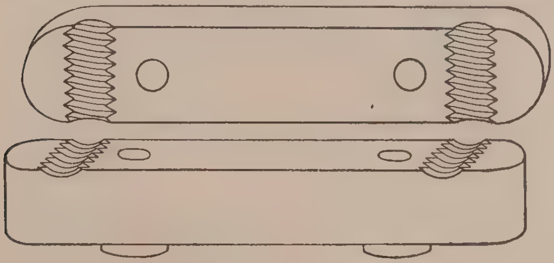


Fig. 19. Two-Wire Cleat.

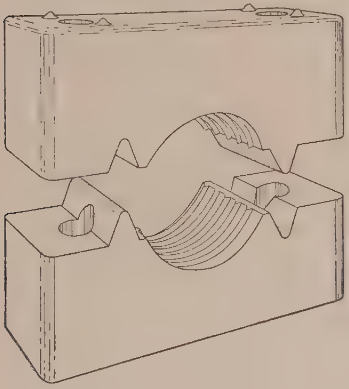


Fig. 20. One-Wire Cleat.

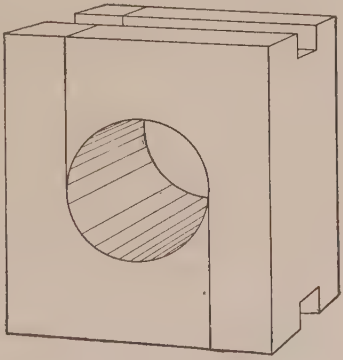


Fig. 21. Porcelain Insulator for Large Conductors.

from No. 6 to No. 4 / 0 B. & S. Gauge, it is usual to use single porcelain cleats or knobs. Figs. 19 and 20 show a good form of two-wire cleat and single-wire cleat, respectively.

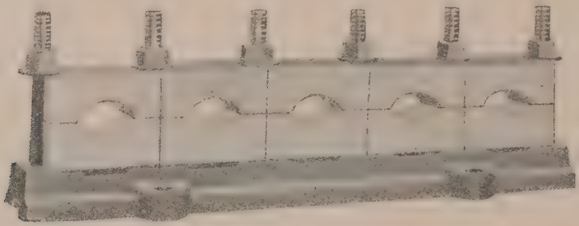


Fig. 22. Iron Rack and Insulators for Large Conductors.
Courtesy of General Electric Co., Schenectady, N. Y.

For large feeder or main conductors from No. 4 / 0 B. & S. Gauge upward, a more substantial form of porcelain insulator should be used, such as shown in Fig. 21. These insulators are held in iron racks or angle-iron frames, of which two forms are shown in Figs. 22 and 23. The latter form of rack is particularly desirable for heavy conductors and where a number of conductors are run together. In this form of rack, any length of conductor can be removed without disturbing the other conductors.

As a rule, the porcelain insulators should be placed not more than 4½ feet apart; and if the wires are liable to be disturbed, the distance between supports should be shortened, particularly for small conductors. If the beams are so far apart that supports cannot be obtained every 4½ feet, it is necessary to provide a running board as shown in Fig. 24, to which the porcelain cleats and knobs can be fastened. Figs. 25 and 26 show two methods of supporting small conductors. For conductors of No. 8 B. & S.

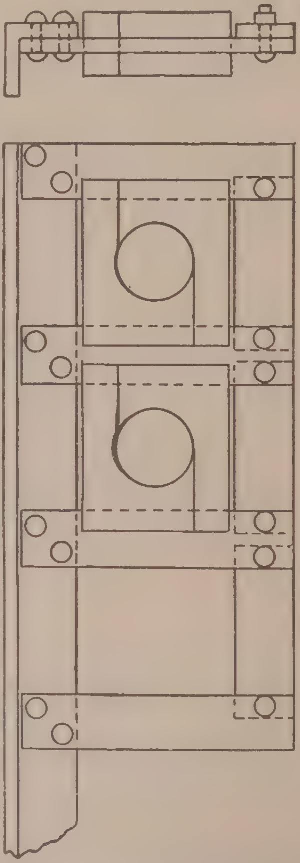


Fig. 23. Elevation and Plan of Insulators Held in Angle-Iron Frames.

Gauge, or over, it is not necessary to break around the beams, provided they are not liable to be disturbed; but the supports may be placed on each beam.

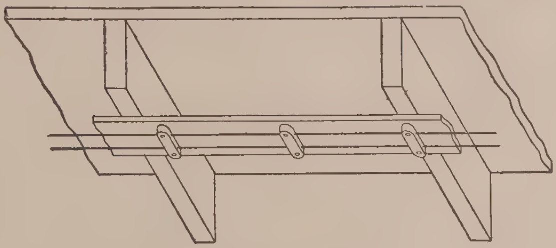


Fig. 24. Insulators Mounted on Running-Board across Wide-Spaced Beams.

Where the distance between the supports, however, is greater than 4½ feet, it is usually necessary to provide intermediate supports, as shown in Fig. 27, or else to provide a running-board. Another method which may be used, where beams are further than 4½ feet apart, is to run a main along the wall at right angles to the beams, and to have the individual circuits run between and parallel to the beams.

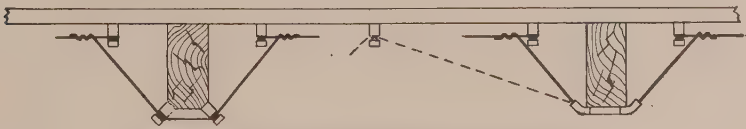


Fig. 25. Method of Supporting Small Conductors.

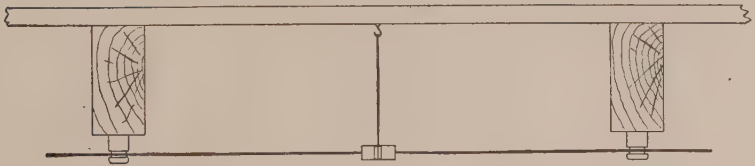


Fig. 27. Intermediate Support for Conductor between Wide-Spaced Beams.

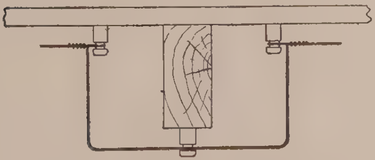


Fig. 26. Method of Supporting a Small Conductor.

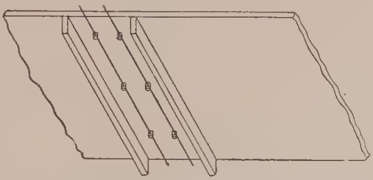


Fig. 28. Conductors Protected by Wooden Guard Strips on Low Ceiling.

In low-ceiling rooms, where the conductors are liable to injury, it is usually required that a wooden guard strip be placed on each side of the conductors, as shown in Fig. 28.

Where the conductors pass through partitions or walls, they must be protected by porcelain tubes, or, if the conductors be of rubber, by means of fibrous tubing placed inside of iron conduits.

All conductors on the walls for a height of not less than six feet from the ground, either should be boxed in, or, if they be rubber-covered, should (preferably) be run in iron conduits; and in conductors having single braid only, additional protection should be provided by means of flexible tubing placed inside of the iron conduit.

Where conductors cross each other, or where they cross iron pipes, they should be protected by means of porcelain tubes fastened with tape or in some other substantial manner that will prevent the tubes from slipping out of place.

TWO-WIRE AND THREE-WIRE SYSTEMS

As both the two-wire and the three-wire system are extensively used in electric wiring, it will be well to give some consideration to the advantages and disadvantages of each system, and to explain them somewhat in detail.

Relative Advantages. The choice of either a two-wire or a three-wire system depends largely upon the source of supply. If, for example, the source of supply will always probably be a 120-volt, two-wire system, there would be no object in installing a three-wire system for the wiring. If, on the other hand, the source of supply is a 120-240-volt system, the wiring should, of course, be made three-wire. Furthermore, if at the outset the supply were two-wire, but with a possibility of a three-wire system being provided later, it would be well to adapt the electric wiring for the three-wire system, making the neutral conductor twice as large as either of the outside conductors, and combining the two outside conductors to make a single conductor until such time as the three-wire service is installed. Of course, there would be no saving of copper in this last-mentioned three-wire system, and in fact it would be slightly more expensive than a two-wire system, as will be shortly explained.

The object of the three-wire system is to reduce the amount of copper—and consequently the cost of wiring—necessary to transmit a given amount of electric power. As a rule, the proposition is usually one of lighting and not of power, for the reason that by means of the three-wire system we are able to increase the potential at which the current is transmitted, and at the same time to take advantage of the greater efficiency of the lower voltage lamp. If current for power (motors, etc.) only were to be transmitted, it would be a simple matter to wind the motors, etc., for a higher voltage, and thereby reduce the weight of copper. If, however, we increase the voltage of lamps, we find that they are not so efficient, nor is their life so long. With the standard carbon lamp, it has been found that the 240-volt lamp, with the same life, requires about 10 to 12 per cent more current than the corresponding 120-volt lamp. Furthermore, in the case of the more efficient lamps recently introduced (such as the Tantalum lamp, Tungsten lamp, etc.), it has been found impracticable, if not impossible, to make them for pressures above 125 volts. For this reason the three-wire system is employed, for by this method we can use 240 volts across the outside conductors, and by the use of a neutral conductor obtain 120 volts between the neutral and the outside conductor, and thereby be enabled to use 120-volt lamps. Furthermore, if a 240-volt lamp should ever be placed on the market that was as economical as the lower voltage lamp, the result would be that the 240-480-volt system would be introduced, and 240-volt lamps used. As a matter of fact, this has been tried in several cities—and particularly in Providence, Rhode Island. As a rule, however, the 120-volt lamp has been found so much more satisfactory as regards life, efficiency, etc., that it is nearly always employed.

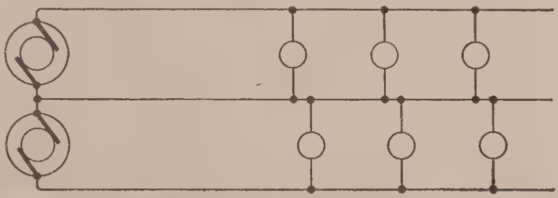


Fig. 29. Three-Wire System, with Neutral Conductor between the Two Outside Conductors.

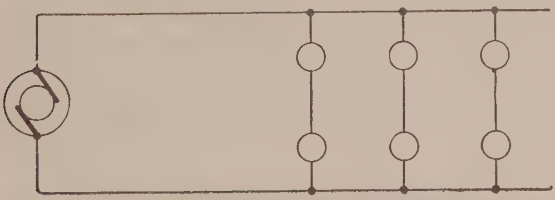


Fig. 30. Lamps Arranged in Pairs in Series, Dispensing with Necessity for Third or Neutral Conductor.

The two-wire system is so extremely simple that no explanation whatever is required concerning it.

The three-wire system, however, is somewhat confusing, and will now be considered.

Details of Three-Wire System. The three-wire system may be considered as a two-wire system with a third or neutral conductor placed between the two outside conductors, as shown in Fig. 29. This neutral conductor would not be required if we could always have the lamps arranged in pairs, as shown in Fig. 30. In this case, the two lamps would burn in series, and we could transmit the current at double the usual voltage, and thereby supply twice the number of lamps with one-quarter the weight of copper, allowing the same loss in pressure in the lamps. The reason for this is, that, having the lamps arranged in series of pairs, we reduce the current to one-half, and, as the pressure at which the current is transmitted is doubled, we can again reduce the copper one-half without increasing the loss in lamps. We therefore see that we have a double saving, as the current is reduced one-half, which reduces the weight of copper one-half, and we can again reduce the copper one-half by doubling the loss in volts without increasing the percentage loss. For example, if in one case we had a straight two-wire system transmitting current to 100 lamps at a potential of 100 volts, and this system were replaced by one in which the lamps were placed in series of pairs, as shown in Fig. 30, and the potential increased to 200 volts—100 lamps still being used—we should find, in the latter case, that we were carrying current really for only 50 lamps, as we would require only the same amount of current for two lamps now that we required for one lamp before. Furthermore, as the potential would now be 200 instead of 100 volts, we could allow twice as much loss as in the first case, because the loss would now be figured as a percentage of 200 volts instead of a percentage of 100 volts. From this, it will readily be seen that in the second case mentioned, we would require only one-quarter the weight of copper that would be required in the first case.

It will readily be seen, however, that a system such as that outlined in the second scheme having two lamps, would be impracticable for ordinary purposes, for the reason that it would always require the lamps to be burned in pairs. Now, it is for this very reason that the third or neutral conductor is required; and, if this conductor be added, it will no longer be necessary to burn the lamps in pairs. This, then, is the object of the three-wire system—to enable us to reduce the amount of copper required for transmitting current, without increasing the electric pressure employed for the lamps.

With regard to the size of the neutral conductor, one important point must be borne in mind; and that is, that the *Rules of the National Electric Code* require the neutral conductor in all interior wiring to be made at least as large as either of the two outside conductors. The reasons for this from a fire standpoint are obvious, because, if for any reason either of the outside conductors became disconnected, the neutral wire might be required to carry the same current as the outside conductors, and therefore it should be of the same capacity. Of course, the chances of such an event happening are slight; but, as the fire hazard is all-important, this rule must be complied with for interior wiring or in all cases where there would be a probability of fire. For outside or underground work, however, where the fire hazard would be relatively unimportant, the neutral conductor might be reduced in size; and, as a matter of fact, it is made smaller than the outside conductors.

The three-wire system is sometimes installed where it is desired to use the system as a two-wire, 125-volt system, or to have it arranged so that it may be used at any time also as a three-wire, 125-250-volt system. Of course, in order to do this, it is necessary to make the neutral conductor equal to the combined capacity of the outside conductors, the latter being then connected together to form one conductor, the neutral being the return conductor. This system is not recommended except in such instances, for example, as where an isolated plant of 125 volts is installed, and where there is a possibility of changing over at some future time to the three-wire, 125-250-volt system. In such a case as this, however, it would be better, where possible, to design the isolated plant for a three-wire, 125-250-volt system originally, and then to make the neutral conductor the same size as each of the two outside conductors.

The weight of copper required in a three-wire system where the neutral conductor is the same size as either of the two outside conductors, is $\frac{3}{8}$ of that required for a corresponding two-wire system using the same voltage of lamps.* It is obvious that this is true, because, as the discussion proved concerning the arrangement shown in Fig. 30, where the lamps were placed in series of pairs, we found that the weight of copper for the two conductors was one-quarter the weight of the regular two-wire system. It is then of course true, that, if we had another conductor of the same size as each of the outside conductors, we increase theweight of copper one-half, or one-quarter plus one-half of one-quarter—that is, three-eighths.

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*NOTE.—If, in the two-wire system, we represent the weight of each of the two conductors by $\frac{1}{2}$, the weight of each of the outside conductors in a three-wire system would be represented by $\frac{1}{8}$; and if we had three conductors of the same size, we would have $\frac{1}{8}+\frac{1}{8}+\frac{1}{8}=\frac{3}{8}$ of the weight of copper required in a three-wire system, which would be required in a corresponding two-wire system having the same percentage of loss and using the same voltage of lamps.

If the neutral conductor were made $\frac{1}{2}$ of the size of each of the outside conductors, as is sometimes done in underground work, the total weight of copper required would be $\frac{1}{8}+\frac{1}{8}+\frac{1}{16}=\frac{5}{16}$ of that required in the corresponding two-wire system.

In the three-wire system frequently used in isolated plants in which the two outside conductors are joined together and the neutral conductor made equal to their combined capacity, there is no saving of copper, for the reason that the same voltage of transmission is used, and, consequently, we have neither reduced the current nor increased the potential. Furthermore, though the weight of copper is the same, it is now divided into three conductors, instead of two, and naturally it costs relatively more to insulate and manufacture three conductors than to insulate and manufacture two conductors having the same total weight of copper. As a matter of fact, the three-wire system, having the neutral conductor equal to the combined capacity of the two outside ones, the latter being joined together, is about 8 to 10 per cent more expensive than the corresponding straight two-wire system.

In interior wiring, as a rule, where the three-wire system is used for the mains and feeders, the two-wire system is nearly always employed for the branch circuits. Of course, the two-wire branch circuits are then balanced on each side of the three-wire system, so as to obtain as far as possible at all times an equal balance on the two sides of the system. This is done so as to have the neutral conductor carry as little current as possible. From what has already been said, it is obvious that in case there is a perfect balance, the lamps are virtually in series of pairs, and the neutral conductor does not carry any current. Where there is an unbalanced condition, the neutral conductor carries the difference between the current on one side and the current on the other side of the system. For example, if we had five lamps on one side of the system and ten lamps on the other, the neutral conductor would carry the current corresponding to five lamps.

In calculating the three-wire system, the neutral conductor is disregarded, the outer wires being treated as a two-wire circuit, and the calculation is for one-half the total number of lamps, the percentage of loss being based on the potential across the two outside conductors.

The three-wire system is very generally employed in alternating-current secondary wiring, as nearly all transformers are built with three-wire connections.

While unbalancing will not affect the total loss in the outside conductors, yet it does affect the loss in the lamps, for the reason that the system is usually calculated on the basis of a perfect balance, and the loss is divided equally between the two lamps (the latter being considered in series of pairs). If, however, there is unbalancing to a great degree, the loss in lamps will be increased; and if the entire load is thrown over on one side, the loss in the lamps will be doubled on the remaining side, because the total loss in voltage will now occur in these lamps, whereas, in the case of perfect balance, it would be equally divided between the two groups of lamps.

CALCULATION OF SIZES OF CONDUCTORS

The formula for calculating the sizes of conductors for direct currents, where the length, load, and loss in volts are given, is as follows:

The size of conductor (in circular mils) is equal to the current *multiplied by* the distance (one way), *multiplied by* 21.6, *divided by* the loss in volts; or,

$$CM = \frac{C \times D \times 21.6}{V} \dots\dots\dots\dots\dots (1)$$

in which C = Current, in amperes;
D = Distance or length of the circuit (one way, in feet);
V = Loss in volts between the beginning and end of the circuit.

The constant (21.6) of this formula is derived from the resistance of a mil foot of wire of 98 per cent conductivity at 25° Centigrade or 77° Fahrenheit. The resistance of a conductor of one mil diameter and one foot long, is 10.8 at the temperature and conductivity named. We multiply this figure (10.8) by 2, as the length of a circuit is usually given as the distance one way, and in order to obtain the resistance of both conductors in a two-wire circuit, we must multiply by 2. The formula as above given, therefore, is for a two-wire circuit; and in calculating the size of conductors in a three-wire system, the calculation should be made on a two-wire basis, as explained hereinafter.

Formula 1 can be transformed so as to obtain the loss in a given circuit, or the current which may be carried a given distance with a stated loss, or to obtain the distance when the other factors are given, in the following manner:

Formula for Calculating Loss in Circuit when Size, Current, and Distance are Given

$$V = \frac{C \times D \times 21.6}{CM} \quad \ldots\ldots\ldots\ldots\ldots (2)$$

Formula for Calculating Current which may be Carried by a Given Circuit of Specified Length, and with a Specified Loss

$$C = \frac{CM \times V}{D \times 21.6} \quad \ldots\ldots\ldots\ldots\ldots (3)$$

Formula for Calculating Length of Circuit when Size, Loss, and Current to be Carried are Given

$$D = \frac{CM \times V}{C \times 21.6} \quad \ldots\ldots\ldots\ldots\ldots (4)$$

Formulæ are frequently given for calculating sizes of conductors, etc., where the load, instead of being given in amperes, is stated in lamps or in horse-power. It is usually advisable, however, to reduce the load to amperes, as the efficiency of lamps and motors is a variable quantity, and the current varies correspondingly.

It is sometimes convenient, however, to make the calculation in terms of watts. It will readily be seen that we can obtain a formula expressed in watts from Formula **1**. To do this, it is advisable to express the loss in volts in percentage, instead of actual volts lost. It must be remembered that, in the above formulæ, V represents the volts lost in the circuit, or, in other words, the difference in potential between the beginning and the end of the circuit, and is not the applied E. M. F. The loss in percentage, in any circuit, is equal to the actual loss expressed in volts, *divided by* the line voltage, *multiplied by* 100; or,

$$P = \frac{V}{E} \times 100.$$

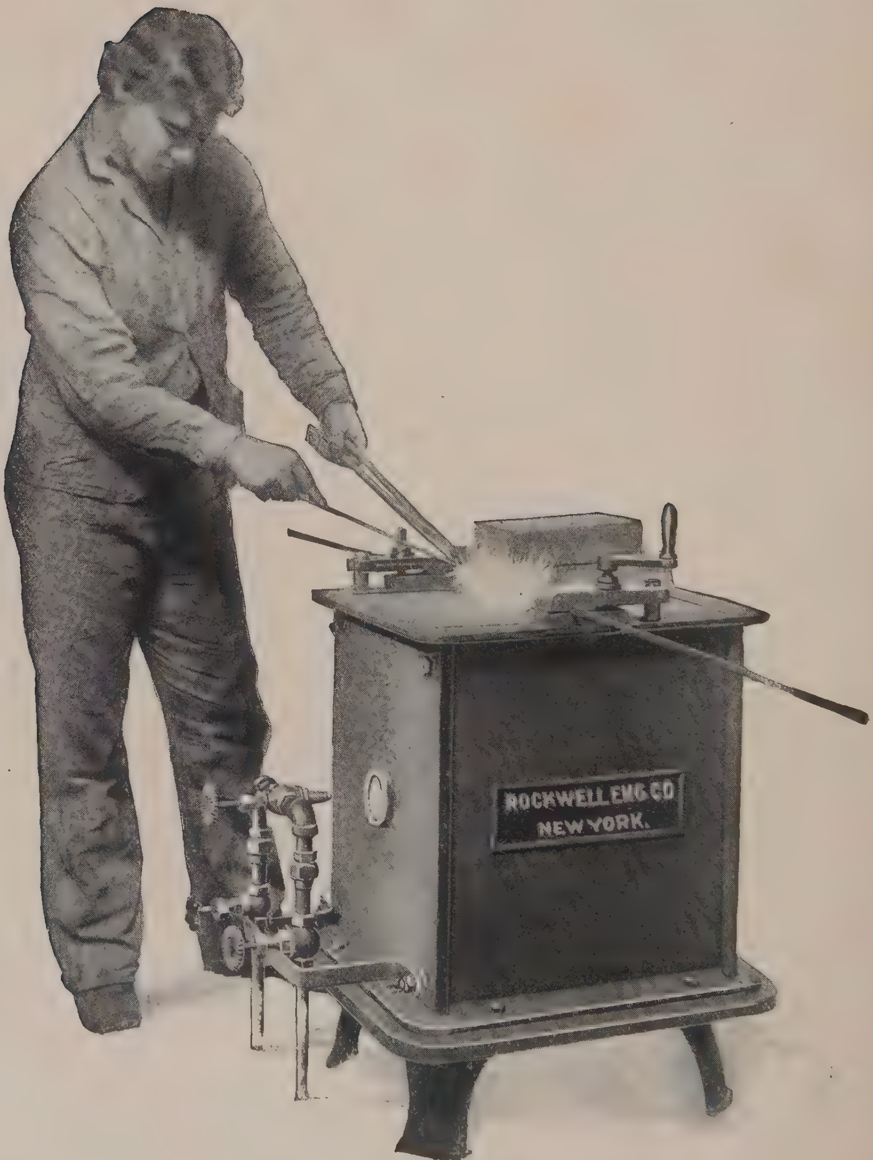
From this equation, we have:

$$V = \frac{P\,E}{100}.$$

If, for example, the calculation is to be made on a loss of 5 per cent, with an applied voltage of 250, using this last equation, we would have:

$$V = \frac{5 \times 250}{100} = 12.5 \text{ volts.}$$

Substituting the equation $V = \frac{P\,E}{100}$ in Formula **1**, we have:



COPPER WIRE BRAZING FURNACE.

Rockwell Engineering Co.

$$C\,M = \frac{C \times D \times 21.6}{\frac{P\,E}{100}}$$

$$= \frac{C \times D \times 21.6 \times 100}{P\,E}$$

$$= \frac{C \times D \times 2{,}160}{P\,E}.$$

This equation, it should be remembered, is expressed in terms of applied voltage. Now, since the power in watts is equal to the applied voltage *multiplied by* the current ($W = EC$), it follows that

$$C = \frac{W}{E}.$$

By substituting this value of C in the equation given above $\left(C\,M = \frac{C \times D \times 2{,}160}{P\,E}\right)$, the formula is expressed in terms of watts instead of current, thus:

$$CM = \frac{W \times D \times 2{,}160}{E\,P\,E}, \ldots\ldots\ldots\ldots \mathbf{(5)}$$

in which W = Power in watts transmitted;
D = Length of the circuit (one way)—that is, the length of one conductor;
P = Figure representing the percentage loss;
E*= Applied voltage.

All the above formulæ are for calculations of two-wire circuits. In making calculations for three-wire circuits, it is usual to make the calculation on the basis of the two outside conductors; and in three wire calculations, the above formulæ can be used with a slight modification, as will be shown.

In a three-wire circuit, it is usually assumed in making the calculation, that the load is equally balanced on the two sides of the neutral conductor; and, as the potential across the outside conductors is double that of the corresponding potential across a two-wire circuit, it is evident that for the same size of conductor the total loss in volts could be doubled without increasing the percentage of loss in lamps. Furthermore, as the load on one side of the neutral conductor, when the system is balanced, is virtually in series with the load on the third side, the current in amperes is usually one-half the sum of the current required by all the lamps. If C be still taken as the total current in amperes (that is, the sum of the current required by all of the lamps) in Formula 1, we shall have to divide this current by 2, to use the formula for calculating the two outside conductors for a three-wire system. Furthermore, we shall have to multiply the voltage lost in the lamps by 2, to obtain the voltage lost in the two outside conductors, for the reason that the potential of the outside conductors is double the potential required by the lamps themselves. In other words, Formula 1 will become:

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*NOTE. Remember that V in Formulæ 1 to 4 represents the volts lost, but that E in Formula 5 represents the applied voltage.

$$CM = \frac{C \times D \times 21.6}{2 \times V \times 2}$$

$$= \frac{C \times D \times 21.6}{4V}, \qquad \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

in which C = Sum of current required by all of the lamps on both sides of the neutral conductor;

D = Length of circuit—that is, of any one of the three conductors;

V = Loss allowed in the lamps, i. e., one-half the total loss in the two outside conductors.

In the same manner, all of the other formulæ may be adapted for making calculations for three-wire systems. Of course the calculation of a three-wire system could be made as if it were a two-wire system, by taking one-half the total number of lamps supplied, at one-half the voltage between the outside conductors.

It is understood, of course, that the size of the conductor in Formula 6 is the size of each of the two outside ones; but, inasmuch as the *Rules of the National Electric Code* require that for interior wiring the neutral conductor shall be at least equal in size to the outside conductors, it is not necessary to calculate the size of the neutral conductor. It must be remembered, however, that, in a three-wire system where the neutral conductor is made equal in capacity to the combined size of the two outside conductors, and where the two outside conductors are joined together, we have virtually a two-wire system arranged so that it can be converted into a three-wire system later. In this case the calculation is exactly the same as in the case of the two-wire circuits, except that one of the two conductors is split into two smaller wires of the same capacity. This is frequently done where isolated plants are installed, and where the generators are wound for 125 volts and it may be desired at times to take current from an outside three-wire 125-250-volt system.

METHOD OF PLANNING A WIRING INSTALLATION

The first step in planning a wiring installation, is to gather all the data which will affect either directly or indirectly the system of wiring and the manner in which the conductors are to be installed. These data will include: Kind of building; construction of building; space available for conductors; source and system of electric-current supply; and all details which will determine the method of wiring to be employed. These last items materially affect the cost of the work, and are usually determined by the character of the building and by commercial considerations.

Method of Wiring. In a modern fireproof building, the only system of wiring to be recommended is that in which the conductors are installed in rigid conduits; although, even in such cases, it may be desirable, and economy may be effected thereby, to install the larger feeder and main conductors exposed on insulators using weatherproof slow-burning wire. This latter method should be used, however, only where there is a convenient runway for the conductors, so that they will not be crowded and will not cross pipes, ducts, etc., and also will not have too many bends. Also, the local inspection authorities should be consulted before using this method.

For mills, factories, etc., wires exposed on cleats or insulators are usually to be recommended, although rigid conduit, flexible conduit, or armored cable may be desirable.

In finished buildings, and for extensions of existing outlets, where the wiring could not readily or conveniently be concealed, moulding is generally used, particularly where cleat wiring or other exposed methods of wiring would be objectionable. However, as has already been said, moulding should not be employed where there is any liability to dampness.

In finished buildings, particularly where they are of frame construction, flexible steel conduits or armored cable are to be recommended.

While in new buildings of frame construction, knob and tube wiring are frequently employed, this method should be used only where the question of first cost is of prime importance. While armored cable will cost approximately 50 to 100 per cent more than knob and tube wiring, the former method is so much more permanent and is so much safer that it is strongly recommended.

Systems of Wiring. The system of wiring—that is, whether the two-wire or the three-wire system shall be used—is usually determined by the source of supply. If the source of supply is an isolated plant, with simple two-wire generators, and with little possibility of current being taken from the outside at some future time, the wiring in the building should be laid out on the two-wire system. If, on the other hand, the isolated plant is three-wire (having three-wire generators, or two-wire generators with balancer sets), or if the current is taken from an outside source, the wiring in the building should be laid out on a three-wire system.

It very seldom happens that current supply from a central station is arranged with other than the three-wire system inside of buildings, because, if the outside supply is alternating current, the transformers are usually adapted for a three-wire system. For small buildings, on the other hand, where there are only a few lights and where there would be only one feeder, the two-wire system is used. As a rule, however, when the current is taken from an outside source, it is best to consult the engineer of the central station supplying the current, and to conform with his wishes. As a matter of fact, this should be done in any event, in order to ascertain the proper voltage for the lamps and for the motors, and also to ascertain whether the central station will supply transformers, meters, and lamps—for, if these are not thus supplied, they should be included in the contract for the wiring.

Location of Outlets. It is not within the scope of this treatise to discuss the matter of *illumination*, but it is desirable, at this point, to outline briefly the method of procedure.

A set of plans, including elevation and details, if any, and showing decorative treatment of the various rooms, should be obtained from the Architect. A careful study should then be made by the Architect, the Owner, and the Engineer, or some other person qualified to make recommendations as to illumination. The location of the outlets will depend: *First*, upon the decorative treatment of the room, which determines the æsthetic and architectural effects; *second*, upon the type and general form of fixtures to be used, which should be previously decided on; *third*, upon the tastes of the owners or occupants in regard to illumination in general, as it is found that tastes vary widely in regard to amount and kind of illumination.

The location of the outlets, and the number of lights required at each, having been determined, the outlets should be marked on the plans.

The Architect should then be consulted as to the location of the centers of distribution, the available points for the risers or feeders, and the available space for the branch circuit conductors.

In regard to the *rising points for the feeders and mains*, the following precautions should be used in selecting chases:

1. The space should be amply large to accommodate all the feeders and mains likely to rise at that given point. This seems trite and unnecessary, but it is the most usual trouble with chases for risers. Formerly architects and builders paid little attention to the requirements for chases for electrical work; but in these later days of 2-inch and 2½-inch conduit, they realize that these pipes are not so invisible and mysterious as the force they serve to distribute, particularly when twenty or more such conduits must be stowed away in a building where no special provision has been made for them.

2. If possible, the space should be devoted solely to electric wiring. Steam pipes are objectionable on account of their temperature; and these and all other pipes are objectionable in the same space occupied by the electrical conduits, for if the space proves too small, the electric conduits are the first to be crowded out.

The chase, if possible, should be continuous from the cellar to the roof, or as far as needed. This is necessary in order to avoid unnecessary bends or elbows, which are objectionable for many reasons.

In similar manner, the location of *cut-out cabinets or distributing centers* should fulfil the following requirements:

1. They should be accessible at all times.
2. They should be placed sufficiently close together to prevent the circuits from being too long.
3. Do not place them in too prominent a position, as that is objectionable from the Architect's point of view.
4. They should be placed as near as possible to the rising chases, in order to shorten the feeders and mains supplying them.

Having determined the system and method of wiring, the location of outlets and distributing centers, the next step is to lay out the *branch circuits* supplying the various outlets.

Before starting to lay out the branch circuits, a drawing showing the floor construction, and showing the space between the top of the beams and girders and the flooring, should be obtained from the Architect. In fireproof buildings of iron or steel construction, it is almost the invariable practice, where the work is to be concealed, to run the conduits over the beams, under the rough flooring, carrying them between the sleepers when running parallel to the sleepers, and notching the latter when the conduits run across them (see Fig. 31). In wooden frame buildings, the conduits run parallel to the beams and to the furring (see Fig. 32); they are also sometimes run below the beams. In the latter case the beams have to be notched, and this is allowable only in certain places, usually near the points where the beams are supported. The Architect's drawing is therefore necessary in order that the location and course of the conduits may be indicated on the plans.

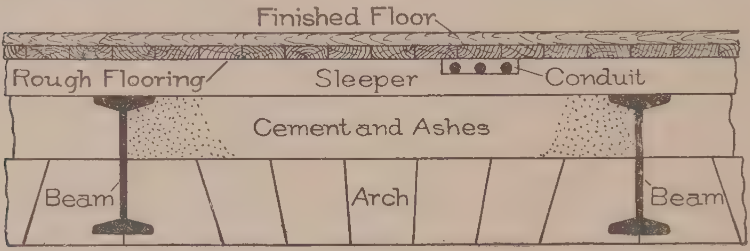


Fig. 31. Running Conductors Concealed under Floor in Fireproof Building.

The first consideration in laying out the branch circuit is the *number of outlets* and *number of lights* to be wired on any one branch circuit. The *Rules of the National Electric Code* (Rule 21-D) require that "no set of incandescent lamps requiring more than 660 watts, whether grouped on one fixture or on several fixtures or pendants, will be dependent on one cut-out." While it would be possible to have branch circuits supplying more than 660 watts, by placing various cut-outs at different points along the route of the branch circuit, so as to subdivide it into small sections to comply with the rule, this method is not recommended, except in certain cases, for exposed wiring in factories or mills. As a rule, the proper method is to have the cut-outs located at the center of distribution, and to limit each branch circuit to 660 watts, which corresponds to twelve or thirteen 50-watt lamps, twelve being the usual limit. Attention is called to the fact that the inspectors usually allow 50 watts for each socket connected to a branch circuit; and although 8-candle-power lamps may be placed at some of the outlets, the inspectors hold that the standard lamp is approximately 50 watts, and for that reason there is always the likelihood of a lamp of that capacity being used, and their inspection is based on that assumption. Therefore, to comply with the requirements, an allowance of not more than twelve lamps per branch circuit should be made.

In ordinary practice, however, it is best to reduce this number still further, so as to make allowance for future extensions or to increase the number of lamps that may be placed at any outlet. For this reason, it is wise to keep the number of the outlets on a circuit at the lowest point consistent with economical wiring. It has been proven by actual practice, that the best results are obtained by limiting the number to five or six outlets on a branch circuit. Of course, where all the outlets have a single light each, it is frequently necessary, for reasons of economy, to increase this number to eight, ten, and, in some cases, twelve outlets.

We have already referred to the location of the wires or conduits. This question is generally settled by the peculiarities of the construction of the building. It is necessary to know this, however, before laying out the circuit work, as it frequently determines the course of a circuit.

Now, as to the course of the circuit work, little need be said, as it is largely influenced by the relative position of the outlets, cut-outs, switches, etc. Between the cut-out box and the first outlet, and between the outlets, it will have to be decided, however, whether the circuits shall run at right angles to the walls of the building or room, or whether they shall run direct from one point to another, irrespective of the angle they make to the sleepers or beams. Of course, in the former case, the advantages are that the cost is somewhat less and the number of elbows and bends is reduced. If the

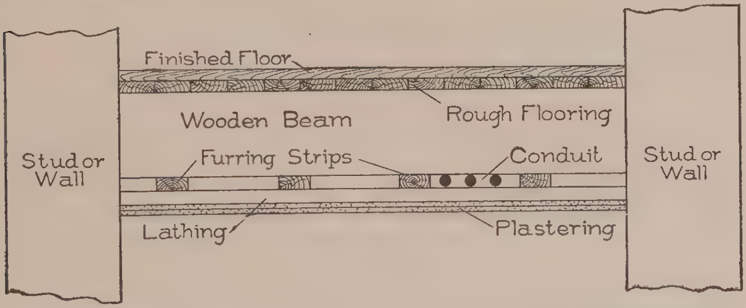


Fig. 32. Running Conductors Concealed under Floor in Wooden Frame Building.

tubes are bent, however, instead of using elbows, the difference in cost is usually very slight, and probably does not compensate for the disadvantages that would result from running the tubes diagonally. As to the number of bends, if branch circuit work is properly laid out and installed, and a proper size of tube used, it rarely happens that there is any difference in "pulling" the branch circuit wires. It may happen, in the event of a very long run or one having a large number of bends, that it might be advisable to adopt a short and most direct route.

Up to this time, the location of the distribution centers has been made solely with reference to architectural considerations; but they must now be considered in conjunction with the branch circuit work.

It frequently happens that, after running the branch circuits on the plans, we find, in certain cases, that the position of centers of distribution may be changed to advantage, or sometimes certain groups may be dispensed with entirely and the circuits run to other points. We now see the wisdom of ascertaining from the Architect where cut-out groups may be located, rather than selecting particular points for their location.

As a rule, wherever possible, it is wise to limit the length of each branch circuit to 100 feet; and the number and location of the distributing centers should be determined accordingly.

It may be found that it is sometimes necessary and even desirable to increase the limit of length. One instance of this may be found in hall or corridor lights in large buildings. It is generally desirable, in such cases, to control the hall lights from one point; and, as the number of lights at each outlet is generally small, it would not be economical to run mains for sub-centers of distribution. Hence, in instances of this character, the length of runs will frequently exceed the limit named. In the great majority of cases, however, the best results are obtained by limiting the runs to 90 or 100 feet.

There are several good reasons for placing such a limit on the length of a branch circuit. To begin with, assuming that we are going to place a limit on the loss in voltage (drop) from the switchboard to the lamp, it may be easily proven that up to a certain reasonable limit it is more economical to have a larger number of distributing centers and shorter branch circuits, than to have fewer centers and longer circuits. It is usual, in the better class of work, to limit the loss in voltage in any branch circuit to approximately one volt. Assuming this limit (one volt loss), it can readily be calculated that the number of lights at one outlet which may be connected on a branch circuit 100 feet long (using No. 14 B. & S. wire), is *four*; or in the case of outlets having a single light each, *five* outlets may be connected on the circuit, the first being 60 feet from the cut-out, the others being 10 feet apart.

These examples are selected simply to show that if the branch circuits are much longer than 100 feet, the loss must be increased to more than one volt, or else the number of lights that may be connected to one circuit must be reduced to a very small quantity, provided, of course, the size of the wire remains the same.

Either of these alternatives is objectionable—the first, on the score of regulation; and the second, from an economical standpoint. If, for instance, the loss in a branch circuit with all the lights turned on is four volts (assuming an extreme case), the voltage at which a lamp on that circuit burns will vary from four volts, depending on the number of lights burning at a time. This, of course, will cause the lamp to burn below candle-power when all the lamps are turned on, or else to diminish its life by burning above the proper voltage when it is the only lamp burning on the circuit. Then, too, if the drop in the branch circuits is increased, the sizes of the feeders and the mains must be correspondingly increased (if the total loss remains the same), thereby increasing their cost.

If the number of lights on the circuit is decreased, we do not use to good advantage the available carrying capacity of the wire.

Of course, one solution of the problem would be to increase the size of the wire for the branch circuits, thus reducing the drop. This, however, would not be desirable, except in certain cases where there were a few long circuits, such as for corridor lights or other special control circuits. In such instances as these, it would be better to increase the sizes of the branch circuit to No. 12 or even No. 10 B. & S. Gauge conductors, than to increase the number of centers of distribution for the sake of a few circuits only, in order to reduce the number of lamps (or loss) within the limit.

The method of calculating the loss in conductors has been given elsewhere; but it must be borne in mind, in calculating the loss of a branch circuit supplying more than one outlet, that separate calculations must be made for each portion of the circuit. That is, a calculation must be made for the loss to the first outlet, the length in this case being the distance from the center of distribution to the first outlet, and the load being the total number of lamps supplied by the circuit. The next step would be to obtain the loss between the first and second outlet, the length being the distance between the two outlets, and the load, in this case, being the total number of lamps supplied by the circuit, *minus* the number supplied by the first outlet; and so on. The loss for the total circuit would be the sum of these losses for the various portions of the circuit.

Feeders and Mains. If the building is more than one story, an elevation should be made showing the height and number of stories. On this elevation, the various distributing centers should be shown diagrammatically; and the current in amperes supplied through each center of distribution, should be indicated at each center. The next step is to lay out a tentative system of feeders and mains, and to ascertain the load in amperes supplied by each feeder and main. The estimated length of each feeder and main should then be determined, and calculation made for the loss from the switchboard to each center of distribution. It may be found that in some cases it will be necessary to change the arrangement of feeders or mains, or even the centers of distribution, in order to keep the total loss from the switchboard to the lamps within the limits previously determined. As a matter of fact, in important work, it is always best to lay out the entire work tentatively in a more or less crude fashion, according to the "cut and dried" method, in order to obtain the best results, because the entire layout may be modified after the first preliminary layout has been made. Of course, as one becomes more experienced and skilled in these matters, the final layout is often almost identical with the first preliminary arrangement.

TESTING

Where possible, two tests of the electric wiring equipment should be made, one after the wiring itself is entirely completed, and switches, cut-out panels, etc., are connected; and the second one after the fixtures have all been installed. The reason for this is that if a ground or short circuit is discovered before the fixtures are installed, it is more easily remedied; and secondly, because there is no division of the responsibility, as there might be if the first test were made only after the fixtures were installed. If the test shows no grounds or short circuits before the fixtures are installed, and one does develop after they are installed, the trouble, of course, is that the short circuit or ground is one or more of the fixtures. As a matter of fact, it is a wise plan always to make a separate test of each fixture after it is delivered at the building and before it is installed.

While a *magneto* is largely used for the purpose of testing, it is at best a crude and unreliable method. In the first place, it does not give an indication, even approximately, of the total insulation resistance, but merely indicates whether there is a ground or short circuit, or not. In some instances, moreover, a magneto test has led to serious errors, for reasons that will be explained. If, as is nearly always the case, the magneto is an alternating-current instrument, it may sometimes happen—particularly in long cables, and especially where there is a lead sheathing on the cable—that the magneto will ring, indicating to the uninitiated that there is a ground or short circuit on the cable. This may be, and usually is, far from being the case; and the cause of the ringing of the magneto is not a ground or short circuit, but is due to the capacity of the cable, which acts as a condenser under certain conditions, since the magneto producing an alternating current repeatedly charges and discharges the cable in opposite directions, this changing of the current causing the magneto to ring. Of course, this defect in a magneto could be remedied by using a commutator and changing it to a direct-current machine; but as the method is faulty in itself, it is hardly worth while to do this.

A portable *galvanometer* with a resistance box and Wheatstone bridge, is sometimes employed; but this method is objectionable because it requires a special instrument which cannot be used for many other purposes. Furthermore, it requires more skill and time to use than the *voltmeter* method, which will now be described.

The advantage of the voltmeter method is that it requires merely a direct-current voltmeter, which can be used for many other purposes, and which all engineers or contractors should possess, together with a box of cells having a potential of preferably over 30 volts. The voltmeter should have a scale of not over 150 volts, for the reason that if the scale on which the battery is used covers too wide a range (say 1,000 volts) the readings might be so small as to make the test inaccurate. A good arrangement would be to have a voltmeter having two scales—say, one of 60 and one of 600—which would make the voltmeter available for all practical potentials that are likely to be used inside of a building. If desired, a voltmeter could be obtained with three connections having three scales, the lowest scale of which would be used for testing insulation resistances.

Before starting a test, all of the fuses should be inserted and switches turned on, so that the complete test of the entire installation can be made. When this has been done, the voltmeter and battery should be connected, so as to obtain on the lowest scale of the voltmeter the electromotive force of the entire group of cells. This connection is shown in Fig. 33. Immediately after this has been done, the insulation resistance to be tested is placed in circuit, whether the insulation to be tested is a switchboard, slate panel-board, or the entire wiring installation; and the connections are made as shown in Fig. 34. A reading should then again be taken of the voltmeter; and the leakage is in proportion to the difference between the first and second readings of the voltmeter. The explanation given below will show how this resistance may be calculated: It is evident that the resistance in the first case was merely the resistance of the voltmeter and the internal resistance of the battery. As a rule, the internal resistance of the battery is so small in comparison with the resistance of the voltmeter and the external resistance, that it may be entirely neglected, and this will be done in the following calculation. In the second case, however, the total resistance in circuits is the resistance of the voltmeter and the battery, *plus* the entire insulation resistance on all the wires, etc., connected in circuit.

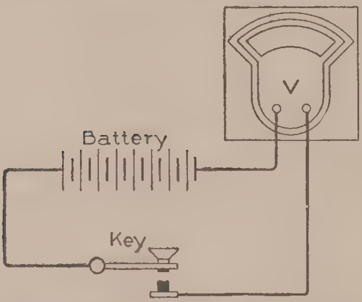


Fig. 33. Connections of Voltmeter and Battery for Testing Insulation Resistance.

To put this in mathematical form, the voltage of the cells may be indicated by the letter E; and the reading of the voltmeter when the insulation resistance is connected by the circuit, by the letter E'. Let R represent the resistance of the voltmeter and R_x represent the insulation resistance of the installation which we wish to measure.

It is a fact which the reader undoubtedly knows, that the E. M. F. as indicated by the voltmeter in Fig. 34 is inversely proportional to the resistance: that is, the greater the resistance, the lower will be the reading on the voltmeter, as this reading indicates the leakage or current passing through the resistance. Putting this in the shape of a formula, we have from the theory of proportion:

$$E : E' :: R + R_x : R\,;$$

or,

$$E' R + E' R_x = E R.$$

Transposing,

$$E' R_x = E R - E' R = R\,(E - E'),$$

and

$$R_x = \frac{R\,(E - E')}{E'}.$$

Or, expressed in words, the insulation resistance is equal to the resistance of the voltmeter *multiplied by* the difference between the first reading (or the voltage in the cells) and the second reading (or the reading of the voltmeter with the insulation resistance in series with the voltmeter), *divided by* this last reading of the voltmeter.

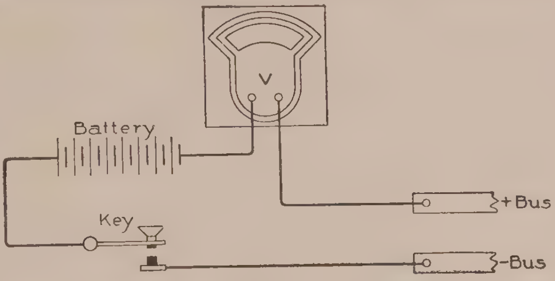


Fig. 34. Insulation Resistance Placed in Circuit, Ready for Testing.

Example. Assume a resistance of a voltmeter (R) of 20,000 ohms, and a voltage of the cells (E) of 30 volts; and suppose that the insulation resistance test of a wiring installation, including switchboard, feeders, branch circuits, panel-boards, etc., is to be made, the insulation resistance being represented by the letter R_x. By substituting in the formula

$$R_x = \frac{R\,(E - E')}{E'},$$

and assuming that the reading of the voltmeter with the insulation resistance connected is 5, we have:

$$R = \frac{20{,}000 \times (30-5)}{5} = 100{,}000 \text{ ohms.}$$

If the test shows an excessive amount of leakage, or a ground or short circuit, the location of the trouble may be determined by the process of elimination—that is, by cutting out the various feeders until the ground or leakage disappears, and, when the feeder on which the trouble exists has been located, by following the same process with the branch circuits.

Of course, the larger the installation and the longer and more numerous the circuits, the greater the leakage will be; and the lower will be the insulation resistance, as there is a greater surface exposed for leakage. The *Rules of the National Electric Code* give a sliding scale for the requirements as to insulation resistance, depending upon the amount of current carried by the various feeders, branch circuits, etc. The rule of the *National Electric Code* (No. 66) covering this point, is as follows:

> "The wiring in any building must test free from grounds; *i. e.*, the complete installation must have an insulation between conductors and between all conductors and the ground (not including attachments, sockets, receptacles, etc.) not less than that given in the following table:

Up to	5	amperes	4,000,000	ohms
"	10	"	2,000,000	"
"	25	"	800,000	"
"	50	"	400,000	"
"	100	"	200,000	"
"	200	"	100,000	"
"	400	"	50,000	"
"	800	"	25,000	"
"	1,600	"	12,500	"

> "The test must be made with all cut-outs and safety devices in place. If the lamp sockets, receptacles, electroliers, etc., are also connected, only one-half of the resistances specified in the table will be required."

ALTERNATING-CURRENT CIRCUITS

It is not within the province of this chapter to treat the various alternating-current phenomena, but simply to outline the modifications which should be made in designing and calculating electric light wiring, in order to make proper allowance for these phenomena.

The most marked difference between alternating and direct current, so far as wiring is concerned, is the effect produced by self-induction, which is characteristic of all alternating-current circuits. This self-induction varies greatly with conditions depending upon the arrangement of the circuit, the medium surrounding the circuit, the devices or apparatus supplied by or connected in the circuit, etc.

For example, if a coil having a resistance of 100 ohms is included in the circuit, a current of one ampere can be passed through the coil with an electric pressure of 100 volts, if direct current is used; while it might require a potential of several hundred volts to pass a current of one ampere if alternating-current were used, depending upon the number of turns in the coil, whether it is wound on iron or some other non-magnetic material, etc.

It will be seen from this example, that greater allowance should be made for self-induction in laying out and calculating alternating-current wiring, if the conditions are such that the self-induction will be appreciable.

On account of self-induction, the two wires of an alternating-current circuit must never be installed in separate iron or steel conduits, for the reason that such a circuit would be virtually a *choke coil* consisting of a single turn of wire wound on an iron core, and the self-induction would not only reduce the current passing through the circuit, but also might produce heating of the iron pipe. It is for this reason that the *National Electric Code* requires conductors constituting a given circuit to be placed in the same conduit, if that conduit is iron or steel, whenever the said circuit is intended to carry, or is liable to carry at some future time, an alternating current. This does not mean, in the case of a two-phase circuit, that all four conductors need be placed in the same conduit, but that the two conductors of a given phase must be placed in the same conduit. If, however, the three-wire system be used for a two-phase system, all three conductors should be placed in the same conduit, as should also be the case in a three-wire three-phase system. Of course, in a single-phase two- or three-wire system, the conductors should all be placed in the same conduit.

In calculating circuits carrying alternating current, no allowance usually should be made for self-induction when the conductors of the same circuit are placed close together in an iron conduit. When, however, the conductors are run exposed, or are separated from each other, calculation should be made to determine if the effects of self-induction are great enough to cause an appreciable inductive drop. There are several methods of calculating this drop due to self-induction—one by formula, and one by a mathematical method which will be described.

Skin Effect. Skin effect in alternating-current circuits is caused by an incorrect distribution of the current in the wire, the current tending to flow through the outer portion of the wire, it being a well-known fact that in alternating currents, the current density decreases toward the center of the conductor, and that in large wires, the current density at the center of the conductor is relatively quite small.

The skin effect increases in proportion to the square of the diameter, and also in direct ratio to the frequency of the alternating current.

For conductors of No. 0000 B. & S. Gauge, and smaller, and for frequencies of 60 cycles per second, or less, the skin effect is negligible and is less than one-half of one per cent.

For very large cables and for frequencies above 60 cycles per second, the skin effect may be appreciable; and in certain cases, allowance for it should be made in making the calculation. In ordinary practice, however, it may be neglected. Table IX, taken from *Alternating-Current Wiring and Distribution,* by W. R. Emmet, gives the data necessary for calculating the skin effect. The figures given in the first and third columns are obtained by multiplying the size of the conductor (in circular mils) by the frequency (number of cycles per second); and the figures in the second and fourth columns show the factor to be used in multiplying the ohmic resistance, in order to obtain the combined resistance and skin effect.

TABLE IX

Data for Calculating Skin Effect

Product of Circular Mils × Cycles per Sec.	Factor	Product of Circular Mils × Cycles per Sec.	Factor
10,000,000	1.00	70,000,000	1.13
20,000,000	1.01	80,000,000	1.17
30,000,000	1.03	90,000,000	1.20
40,000,000	1.05	100,000,000	1.25
50,000,000	1.08	125,000,000	1.34
60,000,000	1.10	150,000,000	1.43

The factors given in this table, *multiplied by* the resistance to direct currents, will give the resistance to alternating currents for copper conductors of circular cross-section.

Mutual Induction. When two or more circuits are run in the same vicinity, there is a possibility of one circuit inducing an electromotive force in the conductors of an adjoining circuit. This effect may result in raising or lowering the E. M. F. in the circuit in which a mutual induction takes place. The amount of this induced E. M. F. set up in one circuit by a parallel current, is dependent upon the current, the frequency, the lengths of the circuits running parallel to each other, and the relative positions of the conductors constituting the said circuits.

Under ordinary conditions, and except for long circuits carrying high potentials, the effect of mutual induction is so slight as to be negligible, unless the conductors are improperly arranged. In order to prevent mutual induction, the conductors constituting a given circuit should be grouped together. Figs. 35 to 39, inclusive, show five arrangements of two two-wire circuits; and show how relatively small the effect of first induction is when the conductors are properly arranged, as in Fig. 38, and how relatively large it may be when improperly arranged, as in Fig. 39. These diagrams are taken from a publication of Mr. Charles F. Scott, entitled *Polyphase Transmission*, issued by the Westinghouse Electric & Manufacturing Company.

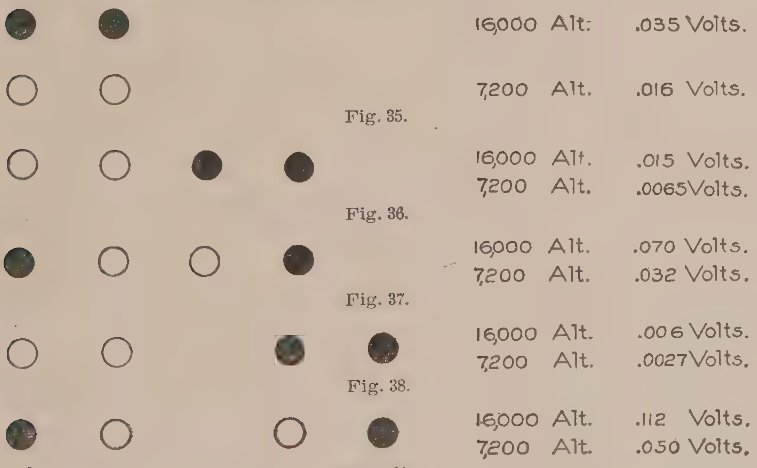


Fig. 35.

Fig. 36.

Fig. 37.

Fig. 38.

Fig. 39.

Various Groupings of Conductors in Two Two-Wire Circuits, Giving Various Effects of Induction.

Line Capacity. The effect of capacity is usually negligible, except in long transmission lines where high potentials are used; no calculations or allowance need be made for capacity, for ordinary circuits.

Calculation of Alternating-Current Circuits. In the instruction paper on "Power Stations and Transmission," a method is given for calculating alternating-current lines by means of formulæ, and data are given regarding power factor and the calculation of both single-phase and polyphase circuits. For short lines, secondary wiring, etc., however, it is probably more convenient to use the chart method devised by Mr. Ralph D. Mershon, described in the *American Electrician* of June, 1897, and partially reproduced as follows:

DROP IN ALTERNATING-CURRENT LINES

When alternating currents first came into use, when transmission distances were short and the only loads carried were lamps, the question of *drop* or *loss of voltage* in the transmitting line was a simple one, and the same methods as for direct current could without serious error be employed in dealing with it. The conditions existing in alternating practice to-day—longer distances, polyphase circuits, and loads made up partly or wholly of induction motors—render this question less simple; and direct-current methods applied to it do not lead to satisfactory results. Any treatment of this or of any engineering subject, if it is to benefit the majority of engineers, must not involve groping through long equations or complex diagrams in search of practical results. The results, if any, must be in available and convenient form. In what follows, the endeavor has been made to so treat the subject of drop in alternating-current lines that if the reader be grounded in the theory the brief space devoted to it will suffice; but if he do not comprehend or care to follow the simple theory involved, he may nevertheless turn the results to his practical advantage.

Calculation of Drop. Most of the matter heretofore published on the subject of drop treats only of the inter-relation of the E. M. F.'s involved, and, so far as the writer knows, there have not appeared in convenient form the data necessary for accurately calculating this quantity. Table X (page 47) and the chart (page 46) include, in a form suitable for the engineer's pocketbook, everything necessary for calculating the drop of alternating-current lines.

The chart is simply an extension of the vector diagram (Fig. 40), giving the relations of the E. M. F.'s of line, load and generator. In

Fig. 40, E is the generator E. M. F.; e, the E. M. F. impressed upon the load; c, that component of E which overcomes the back E. M. F. due to the impedance of the line. The component c is made up of two components at right angles to each other. One is a, the component overcoming the IR or back E. M. F. due to resistance of the line. The other is b, the component overcoming the reactance E. M. F. or back E. M. F. due to the alternating field set up around the wire by the current in the wire. The drop is the difference between E and e. It is d, the radial distance between two circular arcs, one of which is drawn with a radius e, and the other with a radius E.

The chart is made by striking a succession of circular arcs with O as a center. The radius of the smallest circle corresponds to e, the E. M. F. of the load, which is taken as 100 per cent. The radii of the succeeding circles increase by 1 per cent of that of the smallest circle; and, as the radius of the last or largest circle is 140 per cent of that of the smallest, the chart answers for drops up to 40 per cent of the E. M. F. delivered.

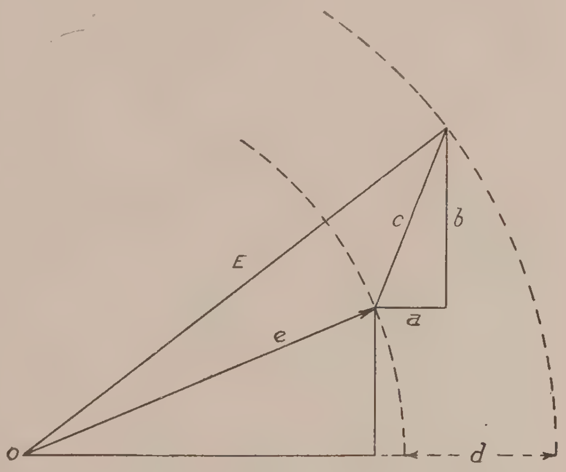


Fig. 40. Vector Diagram.

The terms *resistance volts, resistance E. M. F., reactance volts,* and *reactance E. M. F.*, refer, of course, to the voltages for overcoming the back E. M. F.'s due to resistance and reactance respectively. The figures given in the table under the heading "Resistance-Volts for One Ampere, etc." are simply the resistances of 2,000 feet of the various sizes of wire. The values given under the heading "Reactance-Volts, etc.," are, a part of them, calculated from tables published some time ago by Messrs. Houston and Kennelly. The remainder were obtained by using Maxwell's formula.

The explanation given in the table accompanying the chart

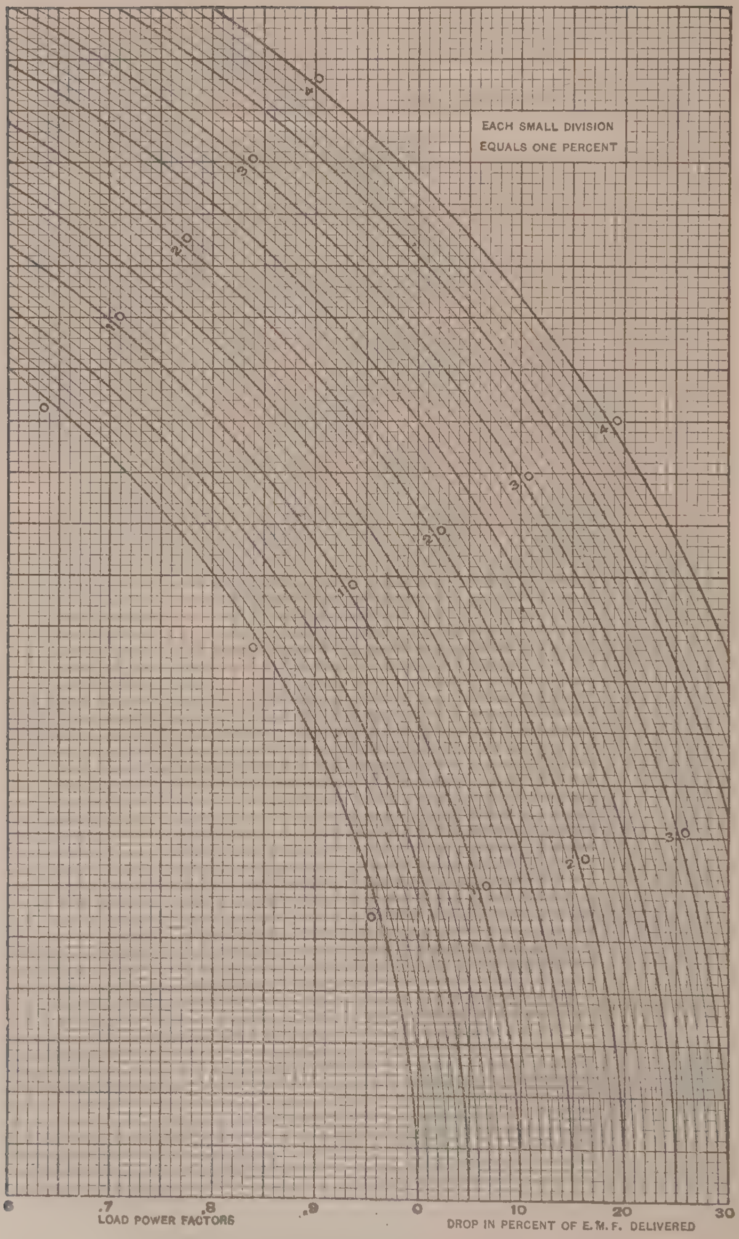


Chart for Calculating Drop in Alternating-Current Lines.

TABLE X

Data for Calculating Drop in Alternating-Current Lines

To be used in conjunction with Chart on opposite page.

By means of the table, calculate the *Resistance-Volts* and the *Reactance-Volts* in the line, and find what per cent each is of the E. M. F. delivered at the end of the line. Starting from the point on the chart where the vertical line corresponding with the power-factor of the load intersects the smallest circle, lay off in per cent the resistance E. M. F. horizontally and to the right; from the point thus obtained, lay off upward in per cent the reactance-E. M. F. The circle on which the last point falls gives the drop, in per cent, of the E. M. F. delivered at the end of the line. Every tenth circle arc is marked with the per cent drop to which it corresponds.

Size of wire—B. & S.	Upper figures are Weight in Lbs. per 1,000 ft. Single Wire	Upper figures are RESISTANCE-VOLTS in 1,000 ft. of Line (2,000 ft. of wire) for One Ampere	Throughout the table the lower figures in the squares give values for ONE MILE of line, corresponding to those of the upper figures for 1,000 feet of line. Upper figures are REACTANCE-VOLTS in 1,000 ft. of Line (= 2,000 ft. of Wire) for One Ampere at 7,200 Alternations per Minute (60 Cycles per Second) for the distance given between Centers of Conductors.										
			½″	1″	2″	3″	6″	9″	12″	18″	24″	30″	36″
0000	639 3,376	.098 .518	.046 .243	.079 .417	.111 .586	.130 .687	.161 .850	.180 .951	.193 1.02	.212 1.12	.225 1.19	.235 1.24	.244 1.29
000	507 2,677	.124 .653	.052 .275	.085 .449	.116 .613	.135 .713	.167 .882	.185 .977	.199 1.05	.217 1.15	.230 1.22	.241 1.27	.249 1.32
00	402 2,123	.156 .824	.057 .301	.090 .475	.121 .639	.140 .739	.172 .908	.190 1.00	.204 1.08	.222 1.17	.236 1.25	.246 1.30	.254 1.34
0	319 1,685	.197 1.04	.063 .332	.095 .502	.127 .671	.145 .766	.177 .935	.196 1.04	.209 1.10	.228 1.20	.241 1.27	.251 1.33	.259 1.37
1	253 1,335	.248 1.31	.068 .359	.101 .533	.132 .687	.151 .797	.183 .966	.201 1.06	.214 1.13	.233 1.23	.246 1.30	.256 1.35	.265 1.40
2	201 1,059	.313 1.65	.074 .391	.106 .560	.138 .728	.156 .824	.188 .993	.206 1.09	.220 1.16	.238 1.26	.252 1.33	.262 1.38	.270 1.43
3	159 840	.394 2.08	.079 .417	.112 .591	.143 .755	.162 .856	.193 1.02	.212 1.12	.225 1.19	.244 1.29	.257 1.36	.267 1.41	.275 1.45
4	126 666	.497 2.63	.085 .449	.117 .618	.149 .787	.167 .882	.199 1.05	.217 1.15	.230 1.22	.249 1.32	.262 1.38	.272 1.44	.281 1.48
5	100 528	.627 3.31	.090 .475	.121 .639	.154 .813	.172 .908	.204 1.08	.223 1.18	.236 1.25	.254 1.34	.268 1.42	.278 1.47	.286 1.51
6	79 419	.791 4.18	.095 .502	.127 .671	.158 .834	.178 .940	.209 1.10	.228 1.20	.241 1.27	.260 1.37	.272 1.44	.283 1.49	.291 1.54
7	63 332	.997 5.27	.101 .533	.132 .697	.164 .866	.183 .966	.214 1.13	.233 1.23	.246 1.30	.265 1.40	.278 1.47	.288 1.52	.296 1.56
8	50 263	1.260 6.64	.106 .560	.138 .729	.169 .893	.188 .993	.220 1.16	.238 1.26	.252 1.33	.270 1.43	.284 1.50	.293 1.55	.302 1.60

(Table X) is thought to be a sufficient guide to its use, but a few examples may be of value.

Problem. Power to be delivered, 250 K.W.; E. M. F. to be delivered, 2,000 volts; distance of transmission, 10,000 feet; size of wire, No. 0; distance between wires, 18 inches; power factor of load, .8; frequency, 7,200 alternations per minute. Find the line loss and drop.

Remembering that the power factor is that fraction by which the apparent power of volt-amperes must be multiplied to give the true power, the apparent power to be delivered is

$$\frac{250 \text{ K.W.}}{.8} = 312.5 \text{ apparent K.W.}$$

The current, therefore, at 2,000 volts will be

$$\frac{312{,}500}{2{,}000} = 156.25 \text{ amperes.}$$

From the table of reactances under the heading "18 inches," and corresponding to No. 0 wire, is obtained the constant .228. Bearing the instructions of the table in mind, the reactance-volts of this line are, 156.25 (amperes) × 10 (thousands of feet) × .228 = 356.3 volts, which is 17.8 per cent of the 2,000 volts to be delivered.

From the column headed "Resistance-Volts" and corresponding to No. 0 wire, is obtained the constant .197. The resistance-volts of the line are, therefore, 156.25 (amperes) × 10 (thousands of feet) × .197 = 307.8 volts, which is 15.4 per cent of the 2,000 volts to be delivered.

Starting, in accordance with the instructions of the table, from the point where the vertical line (which at the bottom of the chart is marked "Load Power Factor" .8) intersects the inner or smallest circle, lay off horizontally and to the right the resistance-E. M. F. in per cent (15.4); and *from the point thus obtained*, lay off vertically the reactance-E. M. F. in per cent (17.8). The last point falls at about 23 per cent, as given by the circular arcs. This, then, is the drop, in per cent, of *the E. M. F. delivered*. The drop, in per cent, of the *generator* E. M. F. is, of course,

$$\frac{23}{100+23} = 18.7 \text{ per cent.}$$

The percentage *loss of power* in the line has not, as with direct current, the same value as the percentage drop. This is due to the fact that the line has reactance, and also that the apparent power delivered to the load is not identical with the true power—that is, the load power factor is less than unity. The loss must be obtained by calculating $I^2 R$ for the line, or, what amounts to the same thing, by multiplying the resistance-volts by the current.

The resistance-volts in this case are 307.8, and the current 156.25 amperes. The loss is $307.8 \times 156.25 = 48.1$ K. W. The percentage *loss* is

$$\frac{48.1}{250 + 48.1} = 16.1 \text{ per cent.}$$

Therefore, for the problem taken, the *drop* is 18.7 per cent, and the *loss* is 16.1 per cent. If the problem be to find the size wire for a given drop, it must be solved by trial. Assume a size of wire and calculate the drop; the result in connection with the table will show the direction and extent of the change necessary in the size of wire to give the required drop.

The effect of the line reactance in increasing the drop should be noted. If there were no reactance, the drop in the above example would be given by the point obtained in laying off on the chart the resistance-E. M. F. (15.4) only. This point falls at 12.4 per cent, and the drop in terms of the generator E. M. F. would be

$$\frac{12.4}{112.4} = 11 \text{ per cent, instead of } 18.7 \text{ per cent.}$$

Anything therefore which will reduce reactance is desirable.

Reactance can be reduced in two ways. One of these is to diminish the distance between wires. The extent to which this can be carried is limited, in the case of a pole line, to the least distance at which the wires are safe from swinging together in the middle of the span; in inside wiring, by the danger from fire. The other way of reducing reactance is to split the copper up into a greater number of circuits, and arrange these circuits so that there is no inductive interaction. For instance, suppose that in the example worked out above, two No. 3 wires were used instead of one No. 0 wire. The resistance-volts would be practically the same, but the reactance-volts would be less in the ratio $\frac{1}{2} \times \frac{.244}{.228} = .535$, since each circuit would bear half the current the No. 0 circuit does, and the constant for No. 3 wire is .244, instead of .228—that for No. 0. The effect of subdividing the copper is also shown if in the example given it is desired to reduce the drop to, say, one-half. Increasing the copper from No. 0 to No. 0000 will not produce the required result, for, although the resistance-volts will be reduced one-half, the reactance-volts will be reduced only in the ratio $\frac{.212}{.228}$. If, however, *two* inductively independent circuits of No. 0 wire be used, the resistance- and reactance-volts will both be reduced one-half, and the drop will therefore be diminished the required amount.

The component of drop due to reactance is best diminished by subdividing the copper or by bringing the conductors closer together. It is little affected by change in size of conductors.

An idea of the manner in which changes of power factor affect drop is best gotten by an example. Assume distance of transmission, distance between conductors E. M. F., and frequency, the same as in the previous example. Assume the *apparent* power delivered the same as before, and let it be constant, but let the power factor be given several different values; the true power will therefore be a variable depending upon the value of the power factor. Let the size of wire be No. 0000. As the apparent power, and hence the current, is the same as before, and the line resistance is one-half, the resistance-E. M. F. will in this case be

$$\frac{15.4}{2}, \text{ or } 7.7 \text{ per cent of the E. M. F. delivered.}$$

Also, the reactance-E. M. F. will be

$$\frac{.212 \times 17.8}{.228} = 16.5 \text{ per cent.}$$

Combining these on the chart for a power factor of .4, and deducing the drop, in per cent, of the generator E. M. F., the value obtained is 15.3 per cent; with a power factor of .8, the drop is 14 per cent; with a power factor of unity, it is 8 per cent. If in this example the *true* power, instead of the *apparent* power, had been taken as constant, it is evident that the values of drop would have differed more widely, since the current, and hence the resistance- and reactance-volts, would have increased as the power factor diminished. The condition taken more nearly represents that of practice.

If the line had resistance and no reactance, the several values of drop, instead of 15.3, 14, and 8, would be 3.2, 5.7, and 7.2 per cent respectively, showing that for a load of lamps the drop will not be much increased by reactance; but that with a load, such as induction motors, whose power factor is less than unity, care should be taken to keep the reactance as low as practicable. In all cases it is advisable to place conductors as close together as good practice will permit.

When there is a transformer in circuit, and it is desired to obtain the combined drop of transformer and line, it is necessary to know the resistance- and reactance-volts of the transformer. The resistance-volts of the combination of line and transformer are the sum of the resistance-volts of the line and the resistance-volts of the transformer. Similarly, the reactance-volts of the line and transformer are the sum of their respective reactance-volts. The resistance- and reactance-E. M. F.s of transformers may usually be obtained from the makers, and are ordinarily given in per cent.* These percentages express the values of the resistance- and reactance-E. M. F.'s when the transformer delivers its normal *full-load* current; and they express these values in terms of the normal *no-load* E. M. F. of the transformer.

Consider a transformer built for transformation between 1,000 and 100 volts. Suppose the resistance- and reactance-E. M. F.'s given are 2 per cent and 7 per cent respectively. Then the corresponding voltages when the transformer delivers full-load current, are 2 and 7 volts or 20 and 70 volts according as the line whose drop is required is connected to the low-voltage or high-voltage terminals. These values, 2—7 and 20—70, hold, no matter at what voltage the trans-

---

*When the required values cannot be obtained from the makers, they may be measured. Measure the resistance of both coils. If the line to be calculated is attached to the high-voltage terminals of the transformer, the equivalent resistance is that of the high-voltage coil, *plus* the resistance obtained by *increasing* in the square of the ratio of transformation the measured resistance of the low-voltage coil That is, if the ratio of transformation is 10, the equivalent resistance referred to the high-voltage circuit is the resistance of the high-voltage coil, *plus* 100 times that of the low-voltage coil. This equivalent resistance multiplied by the high-voltage current gives the transformer resistance-volts referred to the high-voltage circuit. Similarly, the equivalent resistance referred to the low-voltage circuit is the resistance of the low-voltage coil, *plus* that of the high-voltage coil *reduced* in the square of the ratio of transformation. It follows, of course, from this, that the values of the resistance-volts referred to the two circuits bear to each other the ratio of transformation. To obtain the reactance-volts, short-circuit one coil of the transformer and measure the voltage necessary to force through the other coil its normal current at normal frequency. The result is, nearly enough, the reactance-volts. It makes no difference which coil is short-circuited, as the results obtained in one case will bear to those in the other the ratio of transformation. If a close value is desired, subtract from the square of the voltage reading the square of the *resistance*-volts, and take the square root of the difference as the reactance-volts.

former is operated, since they depend only upon the strength of current, providing it is of the normal frequency. If any other than the full-load current is drawn from the transformer, the reactance- and resistance-volts will be such a proportion of the values given above as the current flowing is of the full-load current. It may be noted, in passing, that when the resistance- and reactance-volts of a transformer are known, its regulation may be determined by making use of the chart in the same way as for a line having resistance and reactance.

As an illustration of the method of calculating the drop in a line and transformer, and also of the use of table and chart in calculating low-voltage mains, the following example is given:

Problem. A single-phase induction motor is to be supplied with 20 amperes at 200 volts; alternations, 7,200 per minute; power factor, .78. The distance from transformer to motor is 150 feet, and the line is No. 5 wire, 6 inches between centers of conductors. The transformer reduces in the ratio $\frac{2{,}000}{200}$, has a capacity of 25 amperes at 200 volts, and, when delivering this current and voltage, its resistance-E. M. F. is 2.5 per cent, its reactance-E. M. F. 5 per cent. Find the drop.

The reactance of 1,000 feet of circuit consisting of two No. 5 wires, 6 inches apart, is .204. The reactance-volts therefore are

$$.204 \times \frac{150}{1{,}000} \times 20 = .61 \text{ volts.}$$

The resistance-volts are

$$.627 \times \frac{150}{1{,}000} \times 20 = 1.88 \text{ volts.}$$

At 25 amperes, the resistance-volts of the transformer are 2.5 per cent of 200, or 5 volts. At 20 amperes, they are $\frac{20}{25}$ of this, or 4 volts. Similarly, the transformer reactance-volts at 25 amperes are 10, and at 20 amperes are 8 volts. The combined reactance-volts of transformer and line are $8 + .61 = 8.61$, which is 4.3 per cent of the 200 volts to be delivered. The combined resistance-volts are 1.88 +4, or 5.88, which is 2.94 per cent of the E. M. F. to be delivered. Combining these quantities on the chart with a power factor of .78, the drop is 5 per cent of the delivered E. M. F.,

$$\text{or } \frac{5}{105} = 4.8 \text{ per cent}$$

of the impressed E. M. F. The transformer must be supplied with

$$\frac{2{,}000}{.952} = 2{,}100 \text{ volts,}$$

in order that 200 volts shall be delivered to the motor.

Table X (page 47) is made out for 7,200 alternations, but will answer for any other number if the values for reactance be changed in direct proportion to the change in alternations. For instance, for 16,000 alternations, multiply the reactances given by $\frac{16{,}000}{7{,}200}$. For other distances between centers of conductors, interpolate the values given in the table. As the reactance values for different sizes of wire change by a constant amount, the table can, if desired, be readily extended for larger or smaller conductors.

The table is based on the assumption of sine currents and E. M. F.'s. The best practice of to-day produces machines which so closely approximate this condition that results obtained by the above methods are well within the limits of practical requirements.

Polyphase Circuits. So far, single-phase circuits only have been dealt with. A simple extension of the methods given above adapts them to the calculation of polyphase circuits. A four-wire *quarter-phase* (two-phase) transmission may, so far as loss and regulation are concerned, be replaced by two single-phase circuits identical (as to size of wire, distance between wires, current, and E. M. F.) with the two circuits of the quarter-phase transmission, provided that in both cases there is no inductive interaction between circuits. Therefore, to calculate a four-wire, quarter-phase transmission, compute the single-phase circuit required to transmit one-half the power at the same voltage. The quarter-phase transmission will require two such circuits.

A three-wire, *three-phase* transmission, of which the conductors are symmetrically related, may, so far as loss and regulation are concerned, be replaced by two single-phase circuits having no inductive interaction, and identical with the three-phase line as to size, wire, and distance between wires. Therefore, to calculate a three-phase transmission, calculate a single-phase circuit to carry one-half the load at the same voltage. The three-phase transmission will require three wires of the size and distance between centers as obtained for the single-phase.

A three-wire, quarter-phase transmission may be calculated *exactly* as regards loss, and *approximately* as regards drop, in the same way as for three-phase. It is possible to exactly calculate the drop, but this involves a more complicated method than the approximate one. The error by this approximate method is generally small. It is possible, also, to get a somewhat less drop and loss with the same copper by proportioning the cross-section of the middle and outside wires of a three-wire, quarter-phase circuit to the currents they carry, instead of using three wires of the same size. The advantage, of course, is not great, and it will not be considered here.

WIRING AN OFFICE BUILDING

The building selected as a typical sample of a wiring installation is that of an office building located in Washington, D. C. The figures shown are reproductions of the plans actually used in installing the work.

The building consists of a basement and ten stories. It is of fireproof construction, having steel beams with terra-cotta flat arches. The main walls are of brick and the partition walls of terra-cotta blocks, finished with plaster. There is a space of approximately five inches between the top of the iron beams and the top of the finished floor, of which space about three inches was available for running the electric conduits. The flooring is of wood in the offices, but of concrete, mosaic, or tile in the basement, halls, toilet-rooms, etc.

The electric current supply is derived from the mains of the local illuminating company, the mains being brought into the front of the building and extending to a switchboard located near the center of the basement.

As the building is a very substantial fireproof structure, the only method of wiring considered was that in which the circuits would be installed in iron conduits.

Electric Current Supply. The electric current supply is direct current, two-wire for power, and three-wire for lighting, having a potential of 236 volts between the outside conductors, and 118 volts between the neutral and either outside conductor.

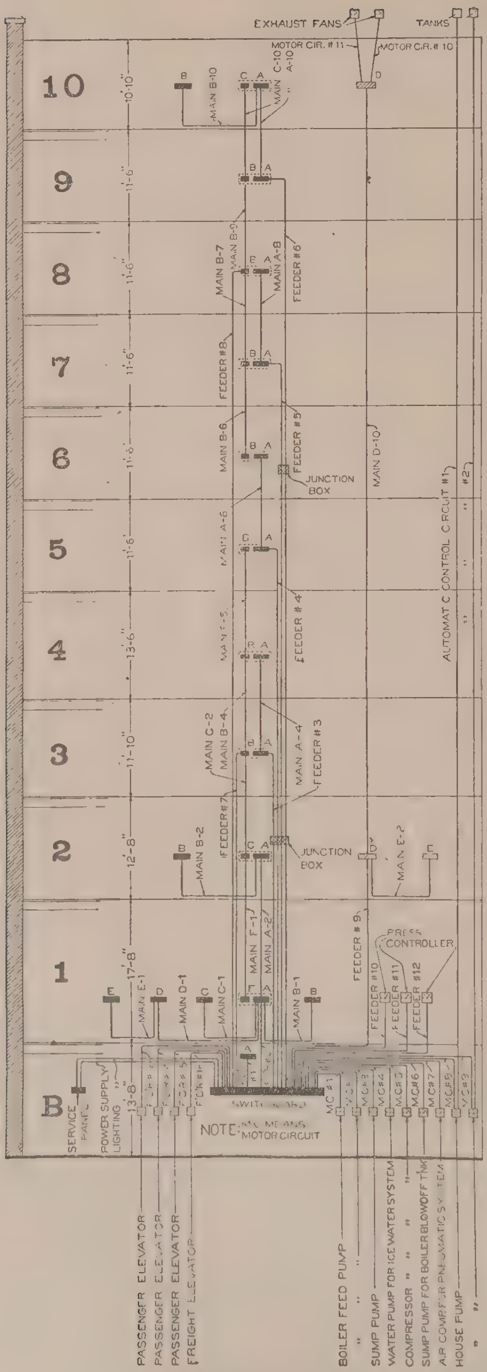
Switchboard. On the switchboard in the basement are mounted wattmeters, provided by the local electric company, and the various switches required for the control and operation of the lighting and power feeders. There are a total of ten triple-pole switches for lighting, and eighteen for power. An indicating voltmeter and ampere meter are also placed in the switchboard. A voltmeter is provided with a double-throw switch, and so arranged as to measure the potential across the two outside conductors, or between the neutral conductor and either of the outside conductors. The ampere meter is arranged with two shunts, one being placed in each outside leg; the shunts are connected with a double-pole, double-throw switch, so that the ampere meter can be connected to either shunt and thus measure the current supplied on each side of the system.

Character of Load. The building is occupied partly as a newspaper office, and there are several large presses in addition to the usual linotype machines, trimmers, shavers, cutters, saws, etc. There are also electrically-driven exhaust fans, house pumps, air-compressors, etc. The upper portion of the building is almost entirely devoted to offices rented to outside parties. The total number of motors supplied was 55; and the total number of outlets, 1,100, supplying 2,400 incandescent lamps and 4 arc lamps.

Feeders and Mains. The arrangement of the various feeders and mains, the cut-out centers, mains, etc., which they supply, are shown diagrammatically in Fig. 41, which also gives in schedule the sizes of feeders, mains, and motor circuits, and the data relating to the cut-out panels.

Although the current supply was to be taken from an outside source, yet, inasmuch as there was a probability of a plant being installed in the building itself at some future time, the three-wire system of feeders and mains was designed, with a neutral conductor equal to the combined capacity of the two outside conductors, so that 120-volt two-wire generators could be utilized without any change in the feeders.

Basement. The plan of the basement, Fig. 42, shows the branch circuit wiring for the outlets in the basement, and the location of the main switchboard. It also shows the trunk cables for the interconnection system serving to provide the necessary wires for telephones,



FEEDERS

NO.	END AT		BRANCH CIR	LIGHTS	LENGTH-FT (ONE WAY)	LOSS IN VOLTS	SIZE OF WIRE		INSIDE DIA. OF CONDUIT ALLOWED *
	FLOOR	CUT-OUT					NO. MIDDLE COND'R	NO. OUTSIDE COND'R	
1	BASMT	A	18	115	48	0.84	2	4	1.25"
2	1 ST	"	83	533	88	1.16	400000	4-0	2.5"
3	3 RD	"	43	288	119	1.68	4-0	0	2"
4	5 TH	"	44	296	147	1.78	250000	2-0	2.5"
5	7 TH	"	"	292	173	1.72	300000	3-0	"
6	9 TH	"	24	365	200	1.61	450000	250000	3"
7	3 RD	B	26	131	119	1.5	0	3	1.5"
8	8 TH	"	27	128	185	1.8	2-0	2	2"
L.S	SW B	"		2165	138	1.5	4000000	2000000	***
9	2 ND	D			148		400000		3"
10	PRESS				83		700000		**
11	"				118		"		"
12	"				"		"		"
13	PASS ELV				58		4-0		2"
14	"				"		"		"
15	"				"		"		"
16	FRGT ELV				148		"		"
P.S	SW B				138		2000000		****

* ALL CONDUCTORS IN ONE CONDUIT.

** SEPARATE CONDUIT FOR EACH CONDUCTOR

*** THIS FEEDER IS TO BE DIVIDED INTO FOUR (4)
" CONDUCTORS OF #2000000 C.M. EACH.
" EACH CONDUCTOR IS TO BE INSTALLED IN A SEP-
" ARATE 3" (INSIDE DIAM.) CONDUIT

L.S.= LIGHTING SUPPLY
P.S.= POWER "

**** SEPARATE 3" (INSIDE DIAM.) CONDUIT FOR EACH
" CONDUCTOR

MAINS

MAINS	SUPPLIED BY			LIGHTS	LENGTH-FT (ONE WAY)	LOSS IN VOLTS	SIZE OF WIRE		INSIDE DIA. OF CONDUIT ALLOWED *
	FEEDER #	CUT OUT	FLOOR				NO. MIDDLE COND'R	NO. OUTSIDE COND'R	
A-2	2	A	1 ST	284	63	0.72	250000	2-0	2.5"
A-4	3	"	3 RD	147	18	0.41	2	4	1.25"
A-6	4	"	5 TH	146	"	0.4	"	"	"
A-8	5	"	7 TH	"	"	"	"	"	"
A-10	6	"	9 TH	171	"	0.29	0	3	1.5"
B-1	2	"	1 ST	76	70	0.51	"	"	"
B-2	"	"	"	106	58	0.58	4-0	0	2"
B-10	6	"	10 TH	87	44	0.37	0	3	1.5"
D-1	2	"	1 ST	120	12	0.22	2	4	1.25"
C-1	"	"	"	70	44	0.30	0	3	1.5"
F-1	7	C	2 ND	22	61	0.41	8	10	1"
C-2	"	B	3 RD	47	18	0.52	"	"	"
B-4	"	"	"	6	"	0.60	"	"	"
B-[illegible]	"	"	4 TH	8	"	0.31	"	"	"
B-[illegible]	8	"	7 TH	2	"	0.35	"	"	"
B-[illegible]	"	"	8 TH	56	"	0.60	"	"	"
B-9	"	"	"	44	"	0.48	"	"	"
C-10	"	"	9 TH	16	"	0.28	10	12	"
E-1	2	A	1 ST	61	92	0.86	2	4	1.25"
E-2	9	D	2 ND		84		0	0	1.5"
D-10	"	"	"		106		2	2	1.25"

* ALL CONDUCTORS IN ONE CONDUIT

MOTOR CIRCUITS

NO.	SUPPLIED BY			H.P. SUPPLIED	CURRENT IN AMP.	LENGTH IN FEET (ONE WAY)	SIZE OF WIRE	INSIDE DIAM. OF CONDUIT ALLOWED *
	FEEDER	CUT OUT	FLOOR					
1			BSMT	15	60	74	2	1.25"
2			"	"	"	"	"	"
3			"	5	20	50	8	1"
4			"	"	"	40	"	"
5			"	15	60	"	2	1.25"
6			"	3	12	48	10	0.75"
7			"		20	"	8	1"
8			"	15	60	80	2	1.25"
9	MAIN		"	"	"	"	"	"
10	D-10	D	10 TH	7.5	30	134	6	1"
11	"	"	"	"	"	28	"	"

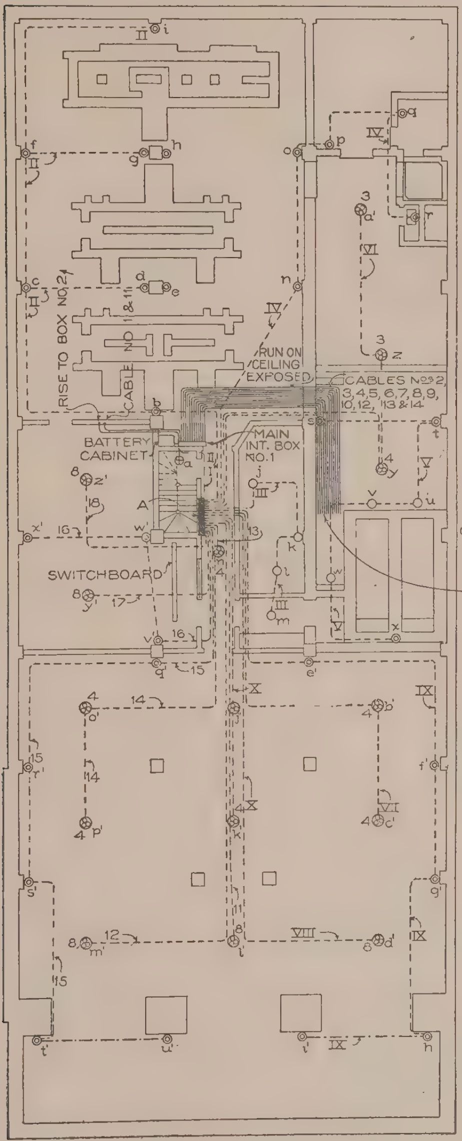
* BOTH CONDUCTORS IN ONE CONDUIT

CUT-OUTS

NAME	FLOOR	HAS CONNECTIONS FOR														
		MAINS	BRANCH CIRCUITS	PB SWITCHES	METERS	KNIFE SWITCHES										
						T.P.S.T.					D.P.S.T.					
						MAIN	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	150
A	BSMT															
[illegible]	1 ST	4					2	1		1						
B	"		10	1												
C	"															
D	"	1	[illegible]	[illegible]												
E	"															
F	"															
A	2 ND	1	16	1												
B	"															
C	"	1	4	4		2										
D	"	1														
E	"															
A	3 RD	1		1												
B	"			4												
A	4 TH		1	1												
B	"	1	4	4												
A	5 TH	1	4	1				2								
B	"		4	4												
A	6 TH		4	1												
B	"		4	1												
A	7 TH	1	4	1				2								
B	"	1	4	4												
A	8 TH		24	1												
B	"		4	4												
A	9 TH	1	24	1				1*	1							
B	"	1	4	4												
A	10 TH	1	24	1			1*	1								
B	"		16	1												
C	"		4	4												
D	"											4	2			

* MAIN SWITCH

Fig. 41. Wiring of an Office Building. Diagram Showing Arrangement of Feeders and Mains, Cut-Out Centers, etc.



SCHEDULE OF CIRCUITS

NO.	SUPPLIED by CUTOUT	SUPPLIED by MAIN	No. of BRANCHES	OUTLETS SUPPLIED	TOTAL OUTLETS	TOTAL LIGHTS	AT WHAT POINT CONTROLLED
I	A	F'D'R NO 1	1	a	1	1	
II	"	"	3	bcdefghi	8	8	
III	"	"	1	jklm	4	4	
IV	"	"	1	nopqr	5	5	
V	"	"	1	stuvwx	6	6	
VI	"	"	1	yza'	3	10	S at A
VII	"	"	1	b'c'	2	8	" " "
VIII	"	"	1	d'	1	8	" " "
IX	"	"	1	e'f'g'h'i'	5	5	
X	"	"	1	j'k'	2	8	S at A
11	"	"	1	l'	1	8	" " "
12	"	"	1	m'	1	8	" " "
13	"	"	1	n'	1	4	" " "
14	"	"	1	o'p	2	8	" " "
15	"	"	1	q'r's't'u'	5	5	
16	"	"	1	v'w'x	3	3	
17	"	"	1	y'	1	8	S at A
18	"	"	1	z'	1	8	" " "
					52	115	

CABLE NO. 2 RISES TO 2nd FLOOR
" " 3 " " 3rd "
" " 4 " " 4th "
" " 5 " " 5th "
" " 6 " " 6th "
" " 7 " " 7th "
" " 8 " " 8th "
" " 9 " " 9th "
" " 10 " " 10th "
" " 12 " " 2nd "
" " 13 " " 5th "
" " 14 " " 8th "

Key Showing Explanation of Various Symbols used in Figs. 41 to 46 Inclusive

- ✧--- ---Ceiling Chandelier
- ⊕--------Wall Bracket
- ◑--------Gooseneck Bracket
- ⊗---- ----Wall Socket
- ○-- -----Drop Cord
- ◐--------Arc Lamp
- ✦--------Cooper-Hewitt Lamp
- ⊛--------Cluster
- ⊙--------Floor Outlet
- ⊙----- --Desk Light
- ⋕--- --Extension Outlet
- ⊥--- --Push Button Switch
- △-------Snap Switch
- ╪--------Junction Box
- ⊕ -------Electric Clock
- ⊠ -------Master Clock
- ☐ -------Motor Starter
- ▬--------Cut-Out Panel
- ▭--------Interconnection Box
- ▨--------Power Panel
- ▤--------Pull Box
- —— —— -----Circuit under Floor
- - - - - - - - - " " " above
- —- —- —- " on Ceiling Exposed
- ———— -----Service Line under Floor

Fig. 42. Wiring an Office Building. Basement Plan Showing Branch Circuit Wiring for Outlets in Basement, Location of Main Switchboard, and Trunk Cables of the Interconnection System Providing Wires for Telephone, Ticker, and Messenger Call Service, etc,

tickers, messenger calls, etc., in all the rooms throughout the building, as will be described later.

To avoid confusion, the feeders were not shown on the basement plan, but were described in detail in the specification, and installed in accordance with directions issued at the time of installation. The electric current supply enters the building at the front, and a service switch and cut-out are placed on the front wall. From this point, a two-wire feeder for power and a three-wire feeder for lighting, are run to the main switchboard located near the center of the basement. Owing to the size of the conduits required for these supply feeders, as well as the main feeders extending to the upper floors of the building, the said conduits are run exposed on substantial hangers suspended from the basement ceiling.

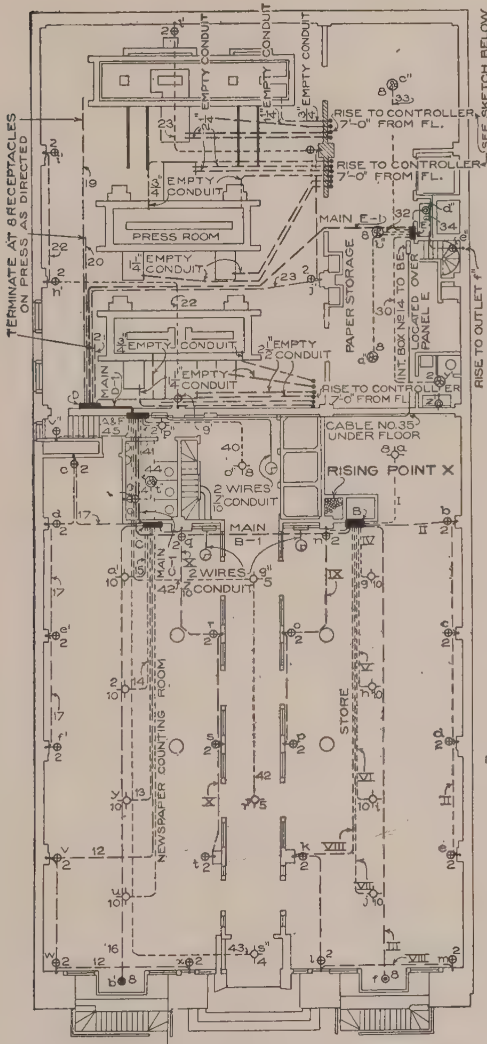
First Floor. The rear portion of the building from the basement through the first floor, Fig. 43, and including the mezzanine floor, between the first and second floors, at the rear portion of the building only, is utilized as a press room for several large and heavy, modern newspaper presses. The motors and controllers for these presses are located on the first floor. A separate feeder for each of these press motors is run directly from the main switchboard to the motor controller in each case. Empty conduits were provided, extending from the controllers to the motor in each case, intended for the various control wires installed by the contractor for the press equipments.

One-half of the front portion of the first floor is utilized as a newspaper office; the remaining half, as a bank.

Second Floor. The rear portion of the second floor, Fig. 44, is occupied as a composing and linotype room, and is illuminated chiefly by means of drop-cords from outlets located over the linotype machines and over the compositors' cases. Separate $\frac{1}{8}$-horse-power motors are provided for each linotype machine, the circuits for the same being run underneath the floor.

Upper Floors. A typical plan (Fig. 45) is shown of the upper floors, as they are similar in all respects with the exception of certain changes in partitions, which are not material for the purpose of illustration or for practical example. The circuit work is sufficiently intelligible from the plan to require no further explanation.

Interconnection System. Fig. 46 is a diagram of the interconnection system, showing the main interconnection box located in the



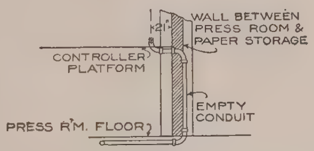
NOTE: ALL CONDUITS FOR THE PRESSES MUST COME THROUGH THE CONTROLLER PLATFORM 21" FROM THE WALL.

ALL CONDUITS ARE TO TERMINATE IN PRESS AS DIRECTED.

SCHEDULE OF CIRCUITS

NO.	SUPPLIED by CUTOUT	SUPPLIED by MAIN	No. of BRANCHES	OUTLETS SUPPLIED	TOTAL OUTLETS	TOTAL LIGHTS	AT WHAT POINT CONTROLLED
I	B	F'D'R No. 2	1	a	1	8	S at B
II	"	"	1	bcde	4	8	" " "
III	"	"	1	f	1	8	" " "
IV	"	"	1	g	1	10	" " "
V	"	"	1	h	1	10	" " "
VI	"	"	1	t	1	10	" " "
VII	"	"	1	j	1	10	" " "
VIII	"	"	1	klm	3	6	" " "
IX	"	"	1	nop	3	6	" " "
			1		16	76	
X	C	C-1	1	qrst	4	8	S at C
11	"	"	1	u	1	10	" " "
12	"	"	1	vwx	3	6	" " "
13	"	"	1	y	1	10	" " "
14	"	"	1	z	1	10	" " "
15	"	"	1	a'	1	10	" " "
16	"	"	1	b'	1	8	" " "
17	"	"	1	c'd'e'f'	4	8	" " "
					16	70	
19	D	D-1	1	8 Receptacles	8	8	
20	"	"	1		8	8	
21	"	"	1		8	8	
22	"	"	1	g'h'i'	3	6	S at D
23	"	"	1	j'k'l'	3	6	" " "
24	SEE MEZZ. PLAN						
25							
26							
27							
28							
29							
30	E	E-1	1	y'z'	2	3	S at E
31	"	"	1	a"	1	8	" " "
32	"	"	1	b"	1	8	" " "
33	"	"	1	c"	1	8	" " "
34	"	"	1	d"e"f", g"	4	4	" " "
35	SEE MEZZ. PLAN						
36							
37							
38							
39							
40	F		1	o"	1	8	S at F
41	"	"	1	p"	1	2	" " "
42	"	"	1	q"r"	2	10	" " "
43	"	"	1	s"	1	4	" " "
44	"	"	1	t"u"	2	6	" " "
45	"	"	1	v"	1	1	" " "
					8	31	" " "

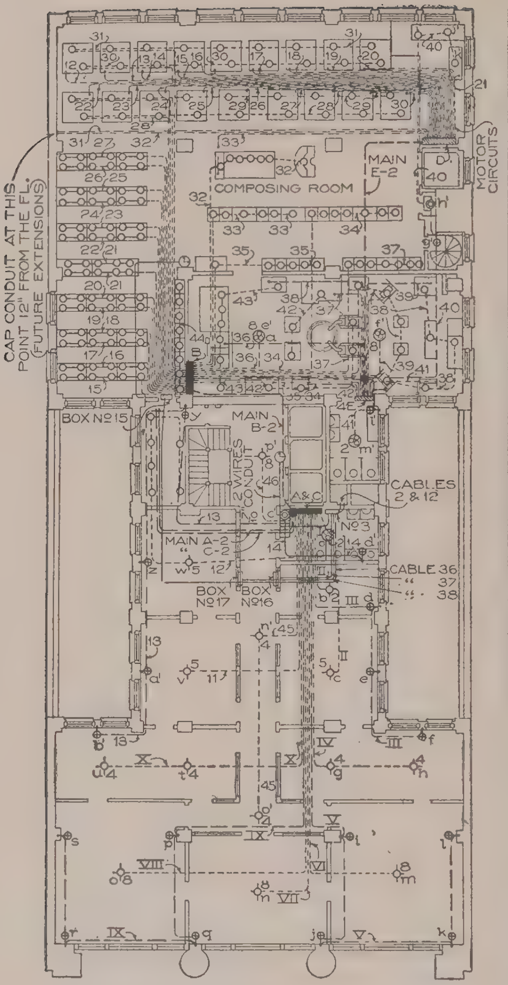
NOTE: THE CLOCKS IN STORE AND COUNTING ROOM ARE TO BE LOCATED AS DIRECTED BY ARCHITECT.



SKETCH SHOWING ROUTE OF EMPTY CONDUITS RISING TO CONTROLLER PLATFORM IN PRESS ROOM.

Fig. 43. Wiring of an Office Building.

First-Floor Plan, Showing Press Room in Rear, Containing Motors and Controllers for Newspaper Presses, Fed Directly from Main Switchboard in Basement; also, in front, Newspaper Counting Room and Bank Offices.



SCHEDULE OF CIRCUITS

NO.	SUPPLIED by CUTOUT	SUPPLIED by MAIN	No. of BRANCHES	OUTLETS SUPPLIED	TOTAL OUTLETS	TOTAL LIGHTS	AT WHAT POINT CONTROLLED
I	A	A-2	1	a	1	2	S at A
II	"	"	1	b c	2	7	
III	"	"	1	d e f	3	3	
IV	"	"	1	g h	2	8	
V	"	"	1	i j k l	4	4	
VI	"	"	1	m	1	8	
VII	"	"	1	n	"	"	
VIII	"	"	1	o	"	"	
IX	"	"	1	p q r s	4	4	
X	"	"	1	t u	2	8	
11	"	"	1	v	1	5	
12	"	"	1	w & 6 Drop Cds	7	"	
13	"	"	1	y z a' b'	4	4	
14	"	"	1	c' d'	2	2	
					30	78	
15	B	B-2	1	Drop Cords	6	6	
16	"	"	1	" "	"	"	
17	"	"	1	" "	"	"	
18	"	"	1	" "	"	"	
19	"	"	1	" "	"	"	
20	"	"	1	" "	"	"	
21	"	"	1	" "	10	10	
22	"	"	1	" "	6	6	
23	"	"	1	" "	"	"	
24	"	"	1	" "	"	"	
25	"	"	1	" "	"	"	
26	"	"	1	" "	"	"	
27	"	"	1	" "	"	"	
28	"	"	1	" "	9	9	
29	"	"	1	" "	"	"	
30	"	"	1	" "	"	"	
31	"	"	1	" "	"	"	
32	"	"	1	" "	7	7	
33	"	"	1	" "	6	6	
34	"	"	1	" "	7	7	
35	"	"	1	" "	6	6	
36	"	"	1	e'	1	8	S at B
37	"	"	1	Drop Cords	7	7	
38	"	"	1	" "	9	9	
39	"	"	1	f'	1	8	S at B
40	"	"	1	g' h' i' j' k'	5	5	
41	"	"	1	l' m'	2	3	S at B
42	"	"	1	Drop Cords	7	7	
43	"	"	1	" "	7	7	
44	"	"	1	" "	8	8	
45	C	C-2	1	n' o'	2	8	S at C
46	"	"	1	p'	1	8	" " "

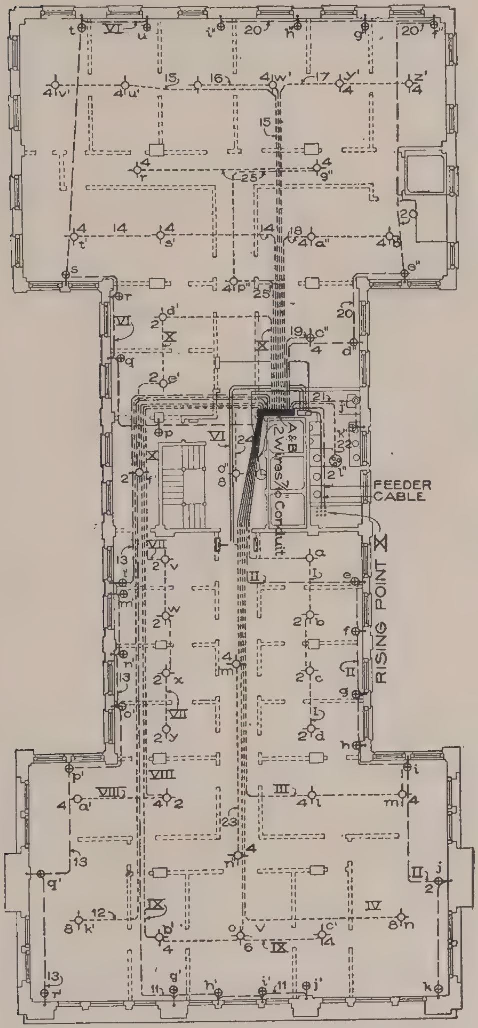
TERMINATE ALL MOTOR CIRCUITS AT MOTOR CONTROLLER AS DIRECTED

MOTOR CIRCUITS

NO.	SUPPLIED BY FEEDER NO.	SUPPLIED BY CUT-OUT	SUPPLIED BY FLOOR	H.P. SUPPLIED	CURRENT IN AMPERES	LENGTH IN FT. (ONE WAY)	SIZE OF WIRE	INSIDE DIA. OF CONDUIT ALLOWED *
12	9	D	2ND	* *		98	10	$\frac{1}{2}$"
13	"	"	"	"		90	"	"
14	"	"	"	"		82	"	"
15	"	"	"	"		76	"	"
16	"	"	"	"		68	"	"
17	"	"	"	"		60	"	"
18	"	"	"	"		52	"	"
19	"	"	"	"		46	"	"
20	"	"	"	"		38	"	"
21	"	"	"	"		28	"	"
22	"	"	"	"		94	"	"
23	"	"	"	"		86	"	"
24	"	"	"	"		78	"	"
25	"	"	"	"		70	"	"
26	"	"	"	"		62	"	"
27	"	"	"	"		54	"	"
28	"	"	"	"		46	"	"
29	"	"	"	"		38	"	"
30	"	"	"	"		30	"	"
31	"	"	"	"		90	"	"
32	"	"	"	"		"	"	"
33	"	"	"	$\frac{1}{4}$		82	"	"
34	"	E	"	3		28	"	"
35	"	"	"	"		32	"	"
36	"	"	"	"		52	"	"
37	"	"	"	"		34	"	"
38	"	"	"	1		48	12	"
39	"	"	"	2		46	10	"
40	"	"	"	3		30	"	"
41	"	"	"	2		28	"	"
42	"	"	"	3		18	"	"

* BOTH CONDUCTORS IN ONE CONDUIT
** $\frac{1}{2}$ H.P. REDUCED TO $\frac{1}{4}$ H.P.

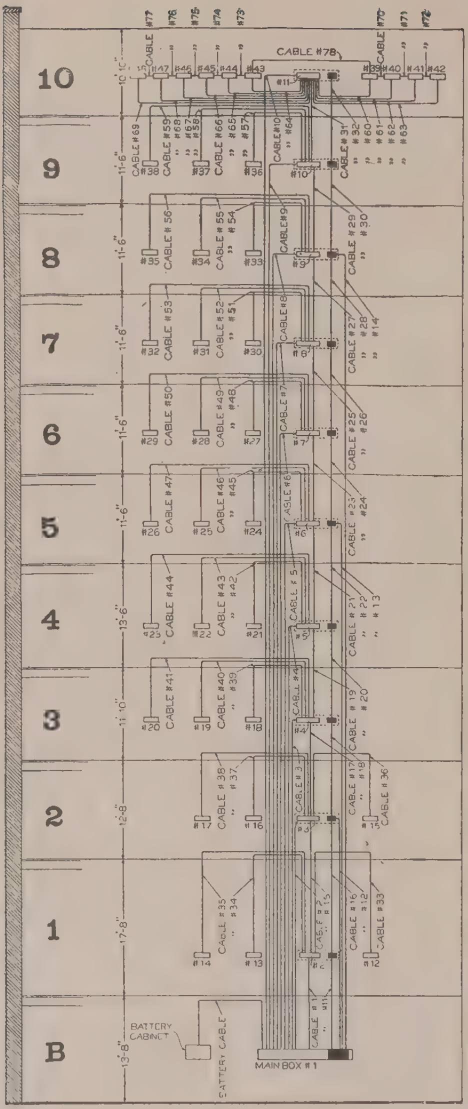
Fig. 44. Wiring of an Office Building. Plan of Second Floor. Rear Portion Occupied as a Composing and Linotype Room.



SCHEDULE OF CIRCUITS

NO.	SUPPLIED by CUTOUT	SUPPLIED by MAIN	No. of BRANCHES	OUTLETS SUPPLIED	TOTAL OUTLETS	TOTAL LIGHTS	AT WHAT POINT CONTROLLED
I	A		1	abcd	4	8	
II	"	"	1	efghijk	7	7	
III	"	"	1	lm	2	8	
IV	"	"	1	n	1	8	
V	"	"	1	o	1	6	
VI	"	"	1	pqrstu	6	6	
VII	"	"	1	vwxy	4	8	
VIII	"	"	1	z a'	2	8	
IX	"	"	1	b'c'	2	8	
X	"	"	1	d'e'f'	3	6	
11	"	"	1	g'h'i'j'	4	4	
12	"	"	1	k'	1	8	
13	"	"	1	l'm'n'o'p'q'r'	7	7	
14	"	"	1	s't'	2	8	
15	"	"	1	u'v'	2	8	
16	"	"	1	w'x'	2	8	
17	"	"	1	y'z'	2	8	
18	"	"	1	a"b"	2	8	
19	"	"	1	c"	1	4	
20	"	"	1	d"e"f"g"h"i"	6	6	
21	"	"	1	j"k"	2	2	
22	"	"	1	l"	1	2	S at A
					64	146	
23	B		1	m"n"	2	8	S at B
24	"	"	1	o"	1	8	S " "
25	"	"	1	p"q"r"	3	12	S " "
					6	28	

Fig. 45. Wiring of an Office Building.
Typical Plan of Upper Floors, Showing Circuit Work, Schedule, etc. All the Floors above the Second are Similar to One Another in Plan, Differing Only in Comparatively Unimportant Details of Partitions.



— CABLES. —

NO.	START AT BOX NO.	START AT FLOOR	END AT BOX NO.	END AT FLOOR	NO OF WIRES	LENGTH IN FEET	INSIDE DIA of CONDUIT ALLOWED
1	1	BASMT	2	1 ST	50	122	1½"
2	"	"	3	2 ND	"	116	"
3	"	"	4	3 RD	"	128	"
4	"	"	5	4 TH	"	139	"
5	"	"	6	5 TH	"	154	"
6	"	"	7	6 TH	"	165	"
7	"	"	8	7 TH	"	176	"
8	"	"	9	8 TH	"	187	"
9	"	"	10	9 TH	"	208	"
10	"	"	11	10 TH	"	219	"
11	"	"	2	1 ST	10	122	¾"
12	"	"	3	2 ND	"	116	"
13	"	"	6	5 TH	"	154	"
14	"	"	9	8 TH	"	187	"
15	2	1 ST	3	2 ND	"	22	1"
16	"	"	"	"	"	"	1½"
17	3	2 ND	4	3 RD	"	16	1"
18	"	"	"	"	"	"	1½"
19	4	3 RD	5	4 TH	"	15	1"
20	"	"	"	"	"	"	1½"
21	5	4 TH	6	5 TH	"	"	1"
22	"	"	"	"	"	"	1½"
23	6	5 TH	7	6 TH	"	"	1"
24	"	"	"	"	"	"	1½"
25	7	6 TH	8	7 TH	"	"	1"
26	"	"	"	"	"	"	1½"
27	8	7 TH	9	8 TH	"	"	1"
28	"	"	"	"	"	"	1½"
29	9	8 TH	10	9 TH	"	"	1"
30	"	"	"	"	"	"	1½"
31	10	9 TH	11	10 TH	"	"	1"
32	"	"	"	"	"	"	1½"
33	2	1 ST	12	1 ST	"	61	1"
34	"	"	13	"	"	22	"
35	"	"	14	"	"	84	"
36	3	2 ND	15	2 ND	"	55	"
37	"	"	16	"	"	26	"
38	"	"	17	"	"	22	"
39	4	3 RD	18	3 RD	"	25	"
40	"	"	19	"	"	53	"
41	"	"	20	"	"	51	"
42	5	4 TH	21	4 TH	"	25	"
43	"	"	22	"	"	53	"
44	"	"	23	"	"	51	"
45	6	5 TH	24	5 TH	"	25	"
46	"	"	25	"	25	53	1¼"
47	"	"	26	"	10	51	1"
48	7	6 TH	27	6 TH	"	25	"
49	"	"	28	"	"	53	"
50	"	"	29	"	"	51	"
51	8	7 TH	30	7 TH	"	25	"
52	"	"	31	"	"	53	"
53	"	"	32	"	"	51	"
54	9	8 TH	33	8 TH	"	25	"
55	"	"	34	"	"	53	"
56	"	"	35	"	"	51	"
57	10	9 TH	36	9 TH	"	25	"
58	"	"	37	"	"	53	"
59	"	"	38	"	"	51	"
60	11	10 TH	39	10 TH	"	29	"
61	"	"	40	"	"	36	"
62	"	"	41	"	"	31	"
63	"	"	42	"	"	39	"
64	"	"	43	"	"	40	"
65	"	"	44	"	"	58	"
66	"	"	45	"	"	79	"
67	"	"	46	"	"	93	"
68	"	"	47	"	"	75	"
69	"	"	48	"	"	56	"
70	39	"	40	"	*	11	"
71	40	"	41	"	"	18	"
72	41	"	42	"	"	13	"
73	43	"	44	"	"	33	"
74	44	"	45	"	"	22	"
75	45	"	46	"	"	"	"
76	46	"	47	"	"	"	"
77	47	"	48	"	"	"	"
78	39	"	43	"	"	"	"

* EMPTY CONDUIT ONLY

— BOXES. —

NO.	FLOOR	NO REQUIRED OF VARIOUS SIZES: FOF	1 A	14-B	16-B	20-B	2 A	3 A				
1	BASMT	1										
2	1 ST			1								
3	2 ND				1							
4	3 RD			1								
5	4 TH			1								
6	5 TH				1							
7	6 TH			1								
8	7 TH			1								
9	8 TH				1							
10	9 TH			1								
11	10 TH					1						
12	1 ST						1					
13	"						1					
14	"						1					
15	2 ND						1					
16	"						1					
17	"						1					
18	3 RD						1					
19	"						1					
20	"						1					
21	4 TH						1					
22	"						1					
23	"						1					
24	5 TH						1					
25	"						1					
26	"						1					
27	6 TH						1					
28	"						1					
29	"						1					
30	7 TH						1					
31	"						1					
32	"						1					
33	8 TH						1					
34	"						1					
35	"						1					
36	9 TH						1					
37	"						1					
38	"						1					
39	10 TH		1									
40	"		1									
41	"		1									
42	"		1									
43	"		1									
44	"		1									
45	"		1									
46	"							1				
47	"		1									
48	"		1									
TOTALS		1	9	6	3	1	27	1				

— FIXTURES. —

LOCATION	BATTERIES	BATTERY CABINET	CLOCKS	MASTER CLOCK								
BASEMENT	28	1										
1 ST FL.			4									
2 ND "			2									
3 RD "			1									
4 TH "			1									
5 TH "			1									
6 TH "			1									
7 TH "			1									
8 TH "			1									
9 TH "			1									
10 TH "			3	1								
				1								
TOTALS	28	1	16	1								

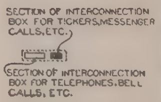

SECTION OF INTERCONNECTION BOX FOR TICKERS, MESSENGER CALLS, ETC.
SECTION OF INTERCONNECTION BOX FOR TELEPHONES, BELL CALLS, ETC.

Fig. 46. Wiring of an Office Building. Diagram of the Interconnection System.

basement; adjoining this main box is located the terminal box of the local telephone company. A separate system of feeders is provided for the ticker system, as these conductors require somewhat heavier insulation, and it was thought inadvisable to place them in the same conduits with the telephone wires, owing to the higher potential of ticker circuits. A separate interconnection cable runs to each floor, for telephone and messenger call purposes; and a central box is placed near the rising point at each floor, from which run subsidiary cables to several points symmetrically located on the various floors. From these subsidiary boxes, wires can be run to the various offices requiring telephone or other service. Small pipes are provided to serve as raceways from office to office, so as to avoid cutting partitions. In this way, wires can be quickly provided for any office in the building without damaging the building in any way whatever; and, as provision is made for a special wooden moulding near the ceiling to accommodate these wires, they can be run around the room without disfiguring the walls. All the main cables and subsidiary wires are connected with special interconnection blocks numbered serially; and a schedule is provided in the main interconnection box in the basement, which enables any wire originating thereat, to be readily and conveniently traced throughout the building. All the main cables and subsidiary cables are run in iron conduits.

OUTLET-BOXES, CUT-OUT PANELS, AND OTHER ACCESSORIES

Outlet-Boxes. Before the introduction of iron conduits, outlet-boxes were considered unnecessary, and with a few exceptions were not used, the conduits being brought to the outlet and cut off after the walls and ceilings were plastered. With the introduction of iron conduits, however, the necessity for outlet-boxes was realized; and the *Rules* of the Fire Underwriters were modified so as to require their use. The *Rules of the National Electric Code* now require outlet-boxes to be used with rigid iron and flexible steel conduits, and with armored cables. A portion of the rule requiring their use is as follows:

All interior conduits and armored cables "must be equipped at every outlet with an approved outlet-box or plate.

"Outlet-plates must not be used where it is practicable to install outlet-boxes.

"In buildings already constructed, where the conditions are such that neither outlet-box nor plate can be installed, these appliances may be omitted by special permission of the inspection department having jurisdiction, providing the conduit ends are bushed and secured."

Fig. 47 shows a typical form of outlet-box for bracket or ceiling outlets of the *universal type.* When it is desired to make an opening for the conduits, a blow from a hammer will remove any of the weakened portion of the wall of the outlet-box, as may be required. This form of outlet-box is frequently referred to as the *knock-out type.* Other forms of outlet-boxes are made with the openings cast in the box at the required points, this class being usually stronger and better made than the universal type. The advantages of the universal type of outlet-box are that one form of box will serve for any ordinary conditions, the openings being made according to the number of conduits and the directions in which they enter the box.

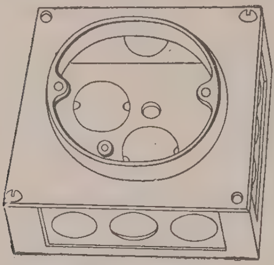


Fig. 47. Universal and Knock-Out Type of Outlet Box.

Fig. 48 shows a waterproof form of outlet-box used out of doors, or in other places where the conditions require the use of a water-tight and waterproof outlet-box.

It will be seen in this case, that the box is threaded for the conduits, and that the cover is screwed on tightly and a flange provided for a rubber gasket.

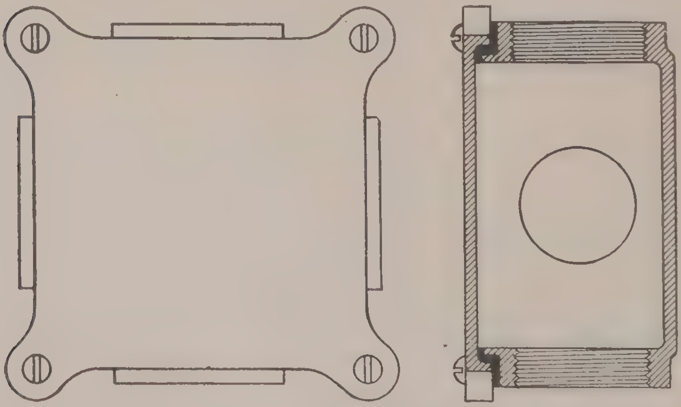


Fig. 48. Water-Tight Outlet Box.
Courtesy of H. Krantz Manufacturing Co., Brooklyn, N. Y.

Figs. 49 and 50 show water-tight floor boxes which are for outlets located in the floor. While the rules do not require that the floor outlet-box shall be water-tight, it is strongly recommended that a water-tight outlet be used in all cases for floor connections. In this case also, the conduit opening is threaded, as well as the stem cover through which the extension is made in the conduit to the desk or table. When the floor outlet connection is not required, the stem cover may be removed and a flat, blank cover be used to replace the same.

A form of outlet-box used for flexible steel cables and steel armored cable, has already been shown (see Fig. 5).

There is hardly any limit to the number and variety of makes of outlet-boxes on the market, adapted for ordinary and for special conditions; but the types illustrated in these pages are characteristic and typical forms.

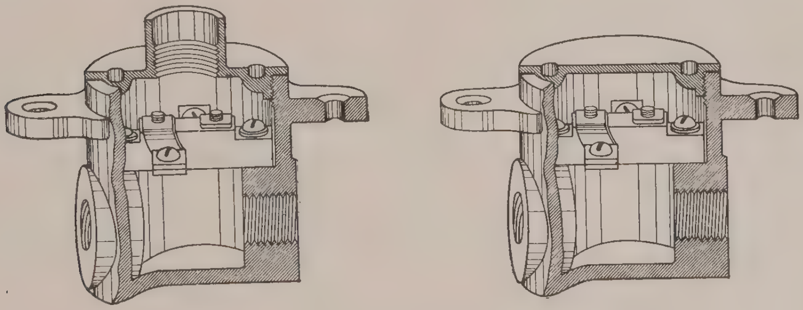


Fig. 49. Fig. 50.

Types of Floor Outlet-Boxes.

Bushings. The *Rules of the National Electric Code* require that conduits entering junction-boxes, outlet-boxes, or cut-out cabinets, shall be provided with approved *bushings,* fitted to protect the wire from abrasion.

Fig. 51 shows a typical form of conduit bushing. This bushing is screwed on the end of the conduit after the latter has been introduced into the outlet-box, cut-out cabinet, etc., thereby forming an insulated orifice to protect the wire at the point where it leaves the conduits, and to prevent abrasion, grounds, short circuits, etc. A lock-nut (Fig. 52) is screwed on the threaded end of the conduit before the conduit is placed in the outlet-box or cut-out cabinet, and this lock-nut and bushing clamp the conduit securely in position. Fig.

53 shows a terminal bushing for panel-boxes used for flexible steel conduit or armored cable.

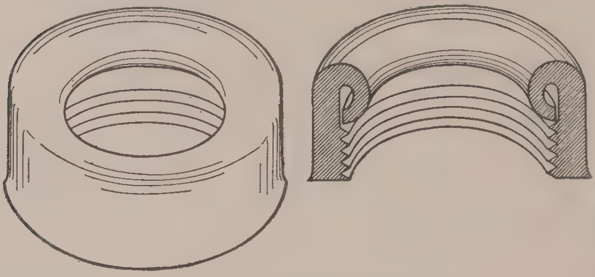


Fig. 51. Conduit Bushing.

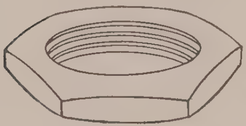


Fig. 52. Lock-Nut.

The *Rules of the National Electric Code* require that the metal of conduits shall be permanently and effectually grounded, so as to insure a positive connection for grounds or leaking currents, and in order to provide a path of least resistance to prevent the current from finding a path through any source which might cause a fire. At outlet-boxes, the conduits and gaspipes must be fastened in such a manner as to insure good electrical connection; and at centers of distribution, the conduits should be joined by suitable bond wires, preferably of copper, the said bond wires being connected to the metal structure of the building, or, in case of a building not having an iron or steel structure, being grounded in a permanent manner to water or gas piping.

Fuse-Boxes, Cut-Out Panels, etc. From the very outset, the necessity was apparent of having a protective device in circuit with the conductor to protect it from overload, short circuits, etc. For this purpose, a fusible metal having a low melting point was employed. The form of this fuse has varied greatly. Fig. 54 shows a characteristic form of what is known as the *link fuse* with copper terminals, on which are stamped the capacity of the fuse.

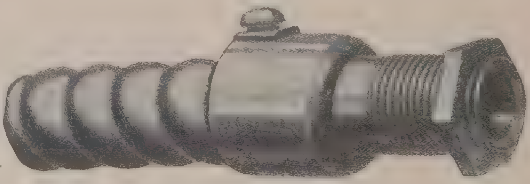


Fig. 53. Panel-Box Terminal Bushing.
Courtesy of Sprague Electric Co., New York, N. Y.

The form of fuse used probably to a greater extent than any other, although it is now being superseded by other more modern forms, is that known as the *Edison fuse-plug,* shown in Fig. 55. A porcelain *cut-out block* used with the Edison fuse is shown in Fig. 56.

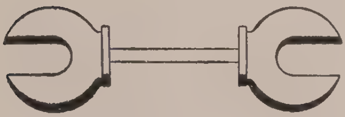


Fig. 54. Copper-Tipped Fuse Link.

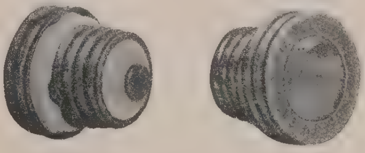


Fig. 55. Edison Fuse-Plug, *Courtesy of General Electric Co., Schenectady, N. Y.*

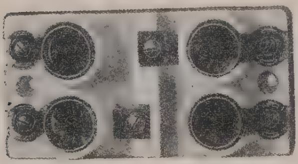


Fig. 56. Porcelain Cut-Out Block. *Courtesy of General Electric Co., Schenectady, N. Y.*

Within the last four or five years, a new form of fuse, known as the *enclosed fuse,* has been introduced and used to a considerable extent. A fuse of this type is shown in Fig. 57. Fig. 58 gives a sectional view of this fuse, showing the porous filling surrounding the fuse-strips, and also the device for indicating when the fuse has blown. This form of fuse is made with various kinds of terminals; it can be used with spring clips in small sizes, and with a post screw contact in larger sizes. For ordinary low potentials this fuse is desirable for currents up to 25 amperes; but it is a debatable question whether it is desirable to use an enclosed fuse for heavier currents. Fig. 59 shows a *cut-out box* with Edison plug fuse-blocks used with knob and tube wiring. It will be seen that there is no connection compartment in this fuse-box, as the circuits enter directly opposite the terminals with which they connect.

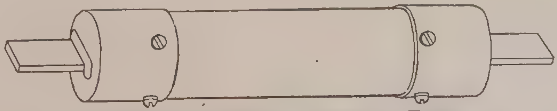


Fig. 57. Enclosed or "Cartridge" Fuse.

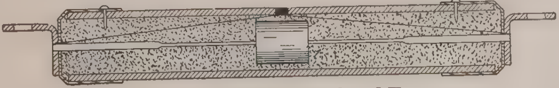


Fig. 58. Section of Enclosed Fuse.

Fig. 60 shows a *cut-out panel* adapted for enclosed fuses, and installed in a cabinet having a connection compartment. As will be seen from the cut, the tablet itself is surrounded on the four sides by slate, which is secured in the corners by angle-irons. The outer box may be of wood lined with sheet iron, or it may be of iron. Fig. 61 shows a door and trim for a cabinet of this type. It will be seen that the door opens only on the center panel, and that the trim covers and conceals the connection compartment. The inner side of the door should be lined with slate, and the inner side of the trim should be lined with sheet iron. Fig. 62 shows a sectional view of the cabinet and panel. In this type of cabinet, the conduits may enter at any point, the wires being run to the proper connectors in the connection compartment.

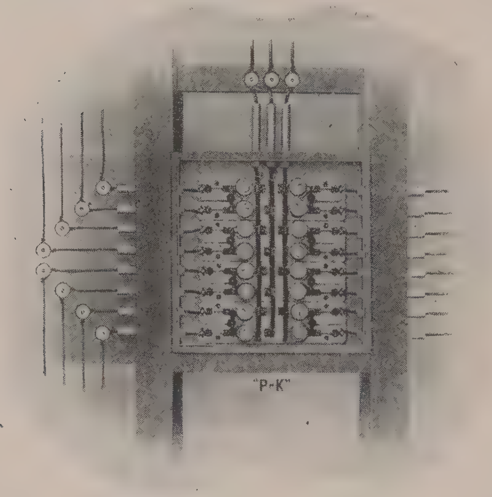


Fig. 59. Porcelain Cut-Outs in Wooden Box.
Courtesy of H. T. Paiste Co., Philadelphia, Pa.

Figs. 63 and 64 illustrate a type of panelboard and cabinet having a push-button switch connected with each branch circuit and so arranged that the cut-out panel itself may be enclosed by locked doors, and access to the switches may be obtained through two separate doors provided with latches only. This type of panel was arranged and designed by the author of this instruction paper.

OVERHEAD LINEWORK

The advantages of overhead linework as compared with underground linework are that it is much less expensive; it is more readily and more quickly installed; and it can be more readily inspected and repaired.

Its principal disadvantages are that it is not so permanent as underground linework; it is more easily deranged; and it is more unsightly.

For large cities, and in congested districts, overhead linework should not be used. However, the question of first cost, the question of permanence, and the municipal regulations, are usually the factors which determine whether overhead or underground linework shall be used.

The principal factors to be considered in overhead linework will be briefly outlined.

Placing of Poles. As a general rule, the poles should be set from 100 to 125 feet apart, which is equivalent to 53 to 42 poles per mile. Under certain conditions, these spacings given will have to be modified; but if the poles are spaced too far apart, there is danger of too great a strain on the poles themselves, and on the cross-arms, pins, and conductors. If, on the other hand, they are placed too close together, the cost is unnecessarily increased. The size and number of conductors, and the potential of the linework, determine to a great extent the distance between the poles; the smaller the size, the less the number of conductors; and the lower the potential, the greater the distance between the poles may be made. Of course, the exact location of the poles is subject to variation because of trees, buildings, or other obstructions. The usual method employed in locating poles, is first to make a map on a fairly large scale, showing the course of the linework, and then to locate the poles on the ground according to the actual conditions.

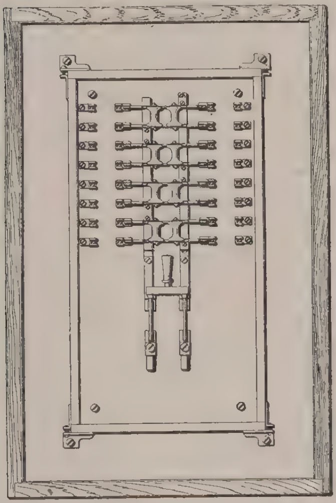


Fig. 60. Plan View, Cover, and Section of Double Cut-Out Box.

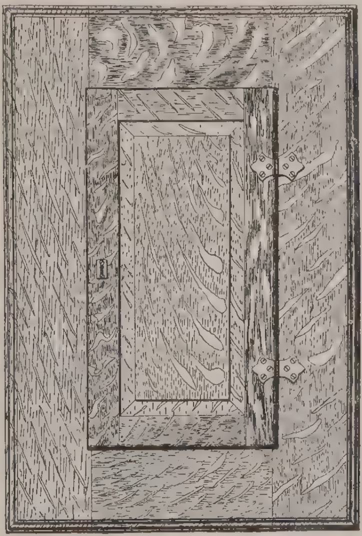


Fig. 61.

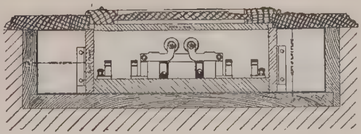


Fig. 62.

Poles. Poles should be of selected quality of chestnut or cedar, and should be sound and free from cracks, knots, or other flaws. Experience has proven that chestnut and cedar poles are the most durable and best fitted for linework. If neither chestnut nor cedar poles can be obtained, northern pine may be used, and even other timber in localities where these poles cannot be obtained; but it is found that the other woods do not last so long as those mentioned, and some of the other woods are not only less strong initially, but are apt to rot much quicker at the "wind and water line"—that is, just above and below the surface of the ground.

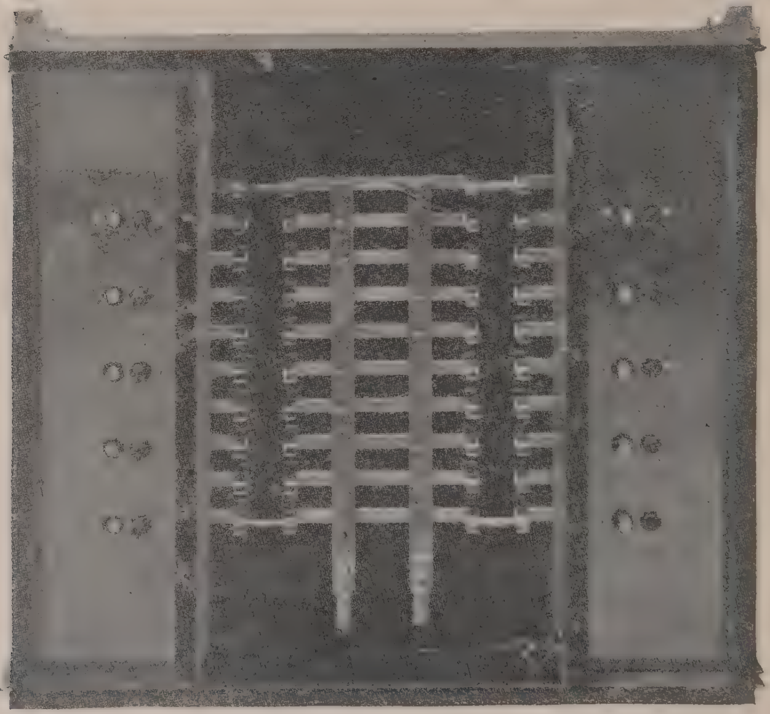


Fig. 63. Cut-Out Panel with Push-Button Switches. Cover Removed.

The proper height of pole to be used depends upon conditions. In country and suburban districts, a pole of 25 to 30 feet is usually of sufficient height, unless there are more than two or three cross-arms required. In more densely populated districts and in cities where a great number of cross-arms are required, the poles may have to be

40 to 60 feet, or even longer. Of course, the longer the pole, the greater the possibility of its breaking or bending; and as the length increases, the diameter of the butt end of pole should also increase. Table X gives the average diameters required for various heights of poles, and the depth the poles should be placed in the ground. These data have been compiled from a number of standard specifications.

TABLE X

Pole Data

LENGTH OF POLE	DIAMETER 6 IN. FROM BUTT	DIAMETER AT TOP	DEPTH POLE SHOULD BE PLACED IN GROUND
25 feet	9 to 10 in.	6 to 8 in.	5 feet
30 “	11 “	“	5½ “
35 “	12 “	“	5½ “
40 “	13 “	“	6 “
45 “	14 “	“	6½ “
50 “	15 “	“	7 “
55 “	16 to 17 “	“	7½ “
60 “	18 “	“	7½ “
65 “	19 “	“	8 “
70 “	20 “	“	8 “
75 “	21 “	“	8½ “
80 “	22 “	“	9 “

As it is somewhat difficult, because of irregularities in size, to measure the diameter of some poles, the circumference may be measured instead; then, by multiplying the diameters given in the above table, by 3,1416, the measurements may be reduced to the circumference in inches.

The minimum diameters of the pole at the top, which should be allowed, will depend largely on the size of the conductors used, and on the potential carried by the circuits; the larger the conductors and the higher the potentials, the greater should be the diameter at the top of the pole.

Poles should be shaved, housed, and gained, also cleaned and ready for painting, before erection.

Poles should usually be painted, not only for the sake of appearance, but also in order to preserve them from the weather. It is particularly important that they should be protected at their butt end, not only where they are surrounded by the ground, but for a foot or two above the ground, as it is at this point that poles usually deteriorate most rapidly. Painting is not so satisfactory at this point as the use of tar, pitch, or creosote. The life of the pole can be increased considerably by treating it with one or another of these preservatives.

Before any poles are erected, they should be closely inspected for flaws and for crookedness or too great departure from a straight line.

Where appearance is of considerable importance, octagonal poles may be used, although these cost considerably more than round poles. *Gains* or notches for the cross-arms should be cut in the poles before they are erected, and should be cut square with the axis of the pole, and so that the cross-arms will fit snugly and tightly within the space thus provided. These gains should be not less than 4½ inches wide, nor less than ½ inch deep. Gains should not be placed closer than 24 inches between centers, and the top gains should be at least 9 inches from the apex of the pole.

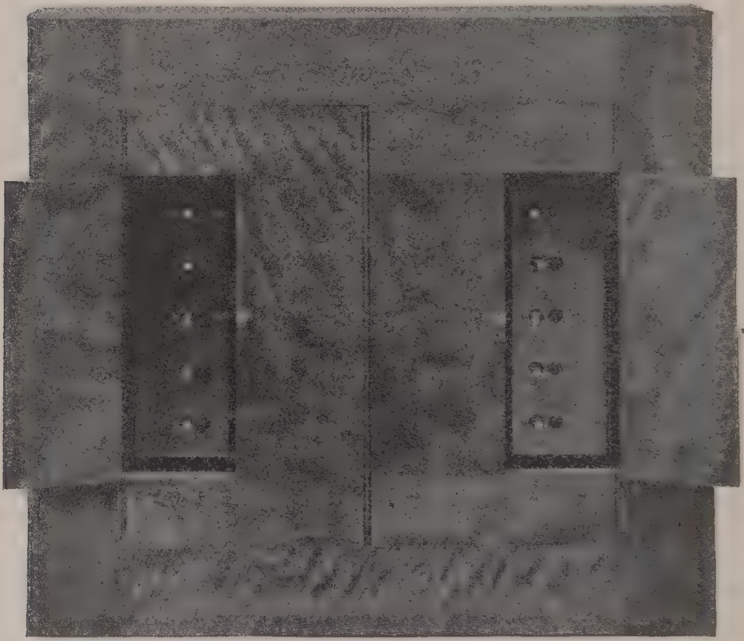


Fig. 64. Cut-Out Panel with Push-Button Switches. With Cover.

ELECTRIC BELL WIRING.

In wiring for electric bells to be operated by batteries, the danger of causing fires from short circuits or poor contacts does not exist as in the case of wiring for light and power, because the current strength is so small. Neither is the bell-fitter responsible to city inspectors or fire underwriters. On this account, bell fitting is too often done in a careless and slovenly manner, causing the apparatus to give unsatisfactory results and to require frequent repairs, so that the expense and inconvenience in the end far more than offset any time saved by doing an inferior grade of work. Hence, at the outset it is well to state that as much care should be taken in the matter of joints and insulation of bell wiring as in wiring for light or power.

If properly installed, the electric bell forms a reliable and yet inexpensive means of signaling, and is far superior to any other. On this account practically every new building is fitted throughout with electric bells.

In addition to the necessity of thoroughness already mentioned, care should be taken to use only reliable apparatus which must be installed in accordance with the fundamental principles on which its satisfactory operation depends.

WIRE.

The common sizes of wire in use for bell work are Nos. 18, 20, and 22. In general, however, No. 20 will be found satisfactory as it is usually sufficiently large, while in many cases No. 22 is not strong enough from a mechanical standpoint.

It is important that the wires should be well insulated to prevent accidental contacts with the staples or other wires. First of all the wire should be tinned, as this prevents the copper from being acted upon by the sulphur in the insulation. It also facilitates soldering. The inner coating of insulation should be of

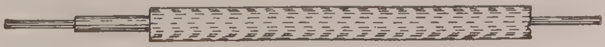


Fig. 1.

india rubber, surrounded by several longitudinal strands of cotton, outside of which are wound several strands of colored cotton laid on spirally. This is next immersed in melted paraffin wax and polished by friction. A short length of approved electric bell wire is shown in Fig. 1.

When ordering wire, it is well to have it furnished in several different colors as this greatly facilitates both the original installation and later repairs, because in this way one line may be distinguished from another, taps from main lines, etc. Moreover, a faulty wire having been found, it is possible to identify it at any desired section of its length.

METHODS OF WIRING.

In running wires, the shortest and most direct route should, of course, be taken between the battery, bells, and bell pushes. There are two cases to be considered. The better method is that in which the wires are run before the building is completed, and the wiring should be done as soon as the roof is on and the walls are up. In this case the wires are usually run in zinc tubes secured to the walls with nails. The tubes should be from $\frac{3}{8}$ inch to $\frac{1}{2}$ inch in diameter, preferably the latter. It is better to place the wires and tubes simultaneously, but the tubes may be put in place first and the wires drawn in afterward, although this latter plan has the objection that the insulation is liable to become abraded when the wires are drawn in. In joining up two lengths of tube, the end of one piece should be opened up with the pliers so that it may receive the end of the other tube, which should also be opened up, but to a less extent, to prevent wear upon the insulation. Specially prepared paper tubes are sometimes substituted for the zinc.

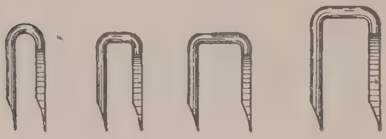


Fig. 2.

If the building is completed before the wiring is done, the concealed method described above cannot be used, and it is necessary to run the wires along the walls supported by staples, where they will be least conspicuous. Fig. 2 shows ordinary double-pointed tacks, Fig. 3 shows an insulating saddle staple which is to be recommended. Two wires should never be secured under the same staple if it can possibly be avoided, owing to the danger of short circuits. With a little care it is usually possible to conceal the wiring behind the picture moulding, along the skirting-board, and beside the door posts, but where it is impossible to conceal it, a light ornamental casing to match the finish of the room, may be used. It is sometimes advisable to use twin wires or two insulated wires run in the same outer covering.

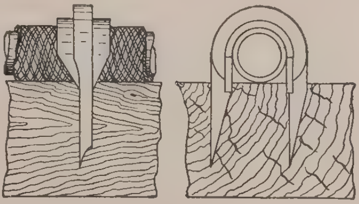


Fig. 3.

In some cases it is well to run the wires under the floors, laying them in notches in the tops of the joists or in holes bored about two inches below the tops of the joists.

JOINTS.

When making a joint, care should be taken to have a firm, clean connection, both mechanically and electrically, and this must always be soldered to prevent corrosion. The insulation should be stripped off the ends of the wires to be joined, for a distance of about 2 inches, and the wires made bright by scraping or sandpapering. They should then be twisted tightly and evenly together as shown in Fig. 4.

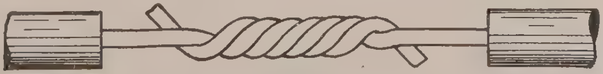


Fig. 4.

Next comes the operation of **soldering,** which is absolutely necessary if a permanent joint from an electrical standpoint is to be obtained. A joint made without solder may be electrically sound at first, but its resistance rapidly increases, due to deterioration of the joint. As has already been stated, the wires should be made bright and clean before they are twisted together. Soldering fluids should never be used, because they cause corrosion of the wire. The best flux to use is resin or composite candle. The soldering should always be done with a copper bit rather than with a blowpipe or wireman's torch.

A convenient form of soldering tool consists of a small copper bit having a semicircular notch near the end. This bit should, of course, be well tinned. It is then heated over a spirit lamp, or wireman's torch, and the notch filled with soft solder. Lay the joint, which has previously been treated with the flux, in this notch and turn it so that the solder runs completely around among the spirals of the joint. The loose solder should be shaken off or removed with a bit of rag. When the joint is set, it should be insulated with rubber tape, so that it will be protected as perfectly as the other portions.

It is often possible to save a considerable length of wire and amount of labor by using a ground return, which, if properly arranged, will give very satisfactory results, although a complete metallic circuit is always to be preferred. Where water or gas mains are available, a good ground may be obtained by connecting to them, being sure to have a good connection. This may be secured by scraping a portion of the pipe perfectly bright and clean and then winding this with bare wire; the whole is then well soldered. An end should be left to which the wire from the bell circuit is twisted and soldered. If such mains are not available, a good ground can be obtained by connecting the wire from the bell circuit, as described above, to a pump pipe. In the absence of water and gas mains, and of a pump pipe, a ground may be obtained by burying beneath permanent moisture level a sheet of copper or lead, having at least five square feet of surface, to which the return wire is connected. The ground plate should be covered with coke nearly to the surface; the hole should then be filled in with ordinary soil well rammed.

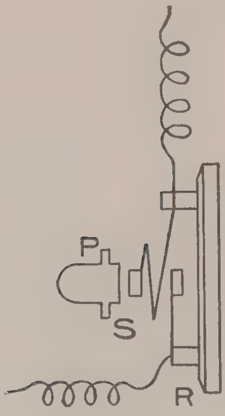


Fig. 5.

OUTFIT.

The three essential parts of the electric bell outfit are the bell push, which furnishes a means of opening and closing the circuit at will, the battery, which furnishes the current for operating the bell, and the bell itself. Before discussing the combination of these pieces of apparatus in the complete circuit, let us take up the individual parts in order.

A bell push is shown diagrammatically in Fig. 5. In this illustration P is the push button; when this is pressed upon it brings the point of the spring S in contact with the metal strip R, thus closing the circuit with which it is connected in series. Normally the springs are separated as shown, and the circuit is accordingly open.

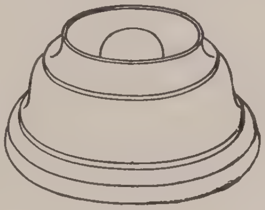


Fig. 6.

Bell pushes are made in various designs and styles, from the simple wooden push shown in Fig. 6 to very elaborate and expensive articles. Fig. 7 shows four cast bronze pushes of neat appearance and moderate price.

Batteries. Electric bells are nearly always operated on the open circuit plan, and hence the battery used is generally of the open circuit type, such as the Leclanche cell, which is used very largely except for heavy work. This is a zinc-carbon cell in which the excitant is sal-ammoniac dissolved in water. Polarization is prevented by peroxide of manganese, which gives up part of its oxygen, combining with the hydrogen set free and forming water.

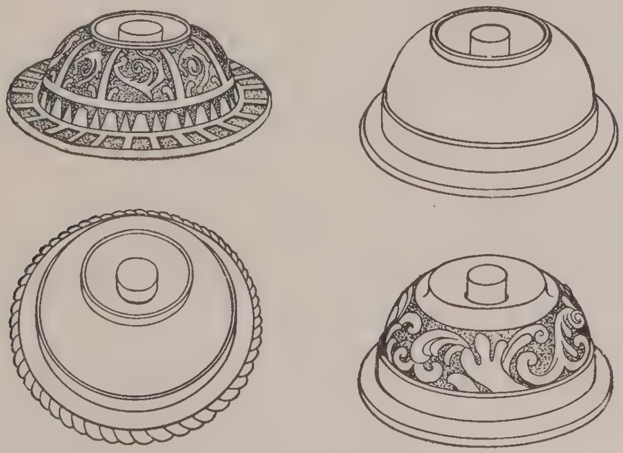


Fig. 7.

Dry Batteries are also frequently used for bell work, their principal advantage being cleanliness, as they cannot spill. Dry cells are really a modification of the Leclanche type, as they use zinc and carbon plates and sal-ammoniac as the exciting agent. The Burnley cell, which is one of the principal types of dry cell, has an electrolyte composed of sal-ammoniac, chloride of zinc, plaster, flour, and water. This compound when mixed is a semi-liquid mass which quickly stiffens after being poured into the cup. The depolarizing agent is peroxide of manganese, the same as is used in the Leclanche cell, this being packed around the carbon cylinder. The top of the cell is sealed with bitumen or some similar substance.

For very heavy work the Edison-Lalande and the Fuller types of cell are best suited, while for closed circuit work the gravity cell is most satisfactory.

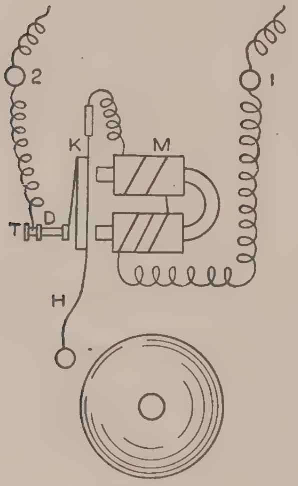


Fig. 8.

Bell. It is a well-known fact that if a current of electricity flows through a coil of wire wound on an iron core, the core becomes magnetized and is capable of attracting any magnetic substances to itself. The operation of the electric bell, like that of so many other pieces of electrical apparatus, depends upon this fact. A diagrammatic representation of an electric bell is shown in Fig. 8, in which M is an electromagnet composed of soft-iron cores on which are wound coils of insulated wire. The armature is mounted upon a spring K, and carries a hammer H at its end for striking the gong. On the back of the armature is a spring which makes contact at D with the back stop T. The action of the bell is as follows: When the circuit is closed through the bell a current flows from terminal 1, around the coils of the magnet, through the spring K and contact point D, through the back stop T, to terminal 2. In flowing around the electromagnet the current magnetizes its core, which consequently attracts the armature. This causes the hammer H to strike the gong. While in this position the contact at D is broken, the current ceases to flow around the electromagnet and the cores consequently lose their attractive force. The armature is then carried back to its original position by the spring K, making contact at D, and the process is repeated. The hammer will thus vibrate and the bell continue to ring as long as the circuit is closed.

The type of bell described above is the one most commonly used. Such bells are made in a great variety of shapes and styles, the prices varying accordingly. It is important that platinum tips be furnished at the contact point D, Fig. 8, to prevent corrosion. The bells on the market today are of two classes, the iron box bell and the wooden box bell. A bell of the wooden box type is shown in Fig. 9, and a higher grade bell of the iron frame skeleton type is shown in Fig. 10. Bells without covers should never be used, as dust will settle on the contacts and interfere with their action.

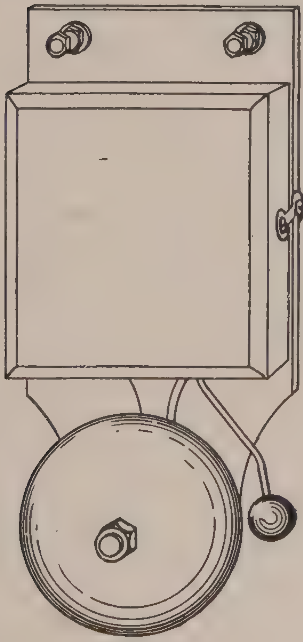


Fig. 9.

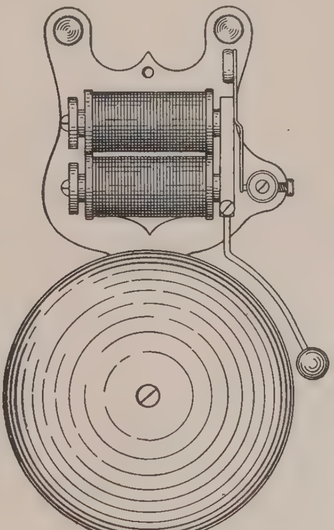


Fig. 10.

CIRCUITS.

The possible combinations of the various parts into complete circuits are so varied that it would be impossible to describe them all; in fact, almost every one is to a certain extent a special problem. It is, however, possible to give typical circuits the underlying principles of which can be applied successfully to any particular case.

Fig. 11 shows a bell circuit in its simplest form, in which P represents the push, B the bell, and C the battery; all connected in series. The circuit is normally open at P, and hence no current flows to exhaust the batteries. When P is pressed, the circuit, otherwise complete, is closed and current passes through the bell causing it to ring, as already explained. For instance, the push might be located beside the front door, the bell in the kitchen and the battery in the cellar; the location depending on the results desired and conditions to be met. The wire between P and C may, if necessary, be dispensed with and connection made to ground at G and G, as shown by the dotted lines.

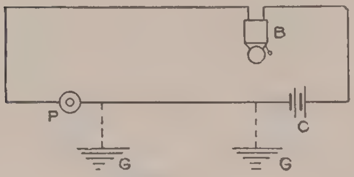


Fig. 11.

Fig. 12 shows an arrangement by means of which one bell B may be controlled by either of the pushes P or P′. This system may be extended to any number of pushes similarly connected.

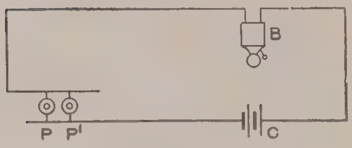


Fig. 12.

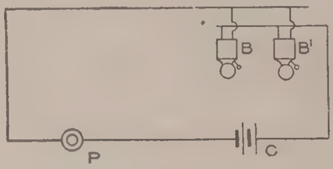


Fig. 13.

A method for ringing two bells simultaneously from one push is shown in Fig. 13, where both bells B and B′ will ring from push P. Bells, if connected in this manner, should have as nearly as possible the same resistance, otherwise the bell of lower resistance will take so much current that there will not be a sufficient amount left for the other. Also, the batteries must be of greater current capacity as the amount of current taken is, of course, doubled. This system can be extended to any number of bells connected in this way, up to the limit of capacity of the battery to ring them. Figs.

12 and 13 may be combined so that two or more bells may be rung from any one of two or more pushes.

In Fig. 14 is shown a scheme for ringing either bell, B or B′, from one push and one battery by means of the two-point switch S. When the arm of the switch is on contact 1, the push will ring bell B, and when on contact 2 it will ring bell B′.

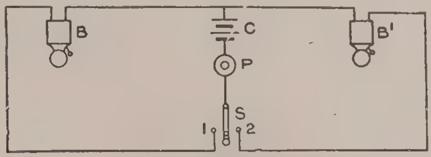


Fig. 14.

In Fig. 15 is shown a method of connecting bells in series so that B and B′ may be rung from P. If all the bells so connected were of the vibrating type, they would not work satisfactorily, as it would be impossible to time them so that the vibrations would keep step, hence only one bell should be of the vibrating type, and the others should have the circuit breakers short-circuited, the vibrating bell serving as interrupter for the whole series. Obviously this system requires a higher voltage than parallel connection, and the cells must be of sufficient E.M.F. to ring the bells satisfactorily. Several bells may be connected in this way, if desired, up to the limit of voltage of the battery.

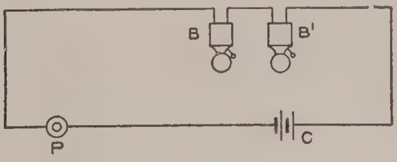


Fig. 15.

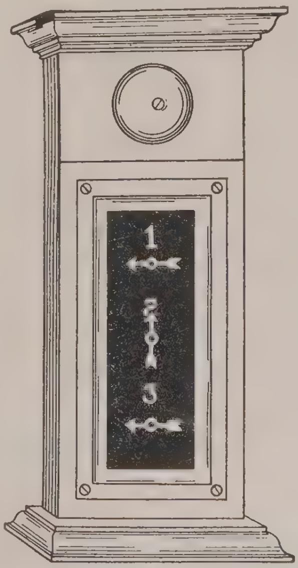


Fig. 16.

Oftentimes a bell is to be rung from several different places. For instance, the bell in an elevator may be rung from any one of several floors, or the bell in the office of a hotel may be rung from any one of several different rooms. In this case it is necessary to have some device to indicate from which push the bell was rung. The annunciator furnishes this information very well. A three-station annunciator is shown in Fig. 16. The connections for an annunciator are shown in Fig. 17 where A represents the annunciator, B the bell, C the battery, and P^1, P^2, and P^3 the pushes. For instance, when P^1 is pressed, the current passes through the electromagnet controlling point 1 on the annunciator which causes the arrow to be turned and at the same time the bell rings. After the attendant has noted the signal, the arrow is restored to its normal position by pressing a lever on the bottom of the annunciator box.

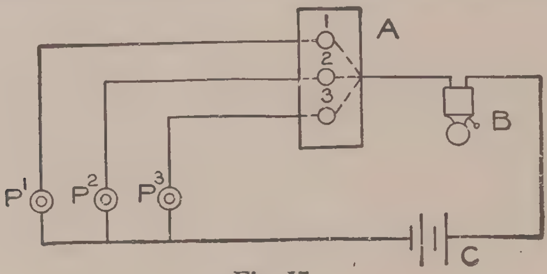
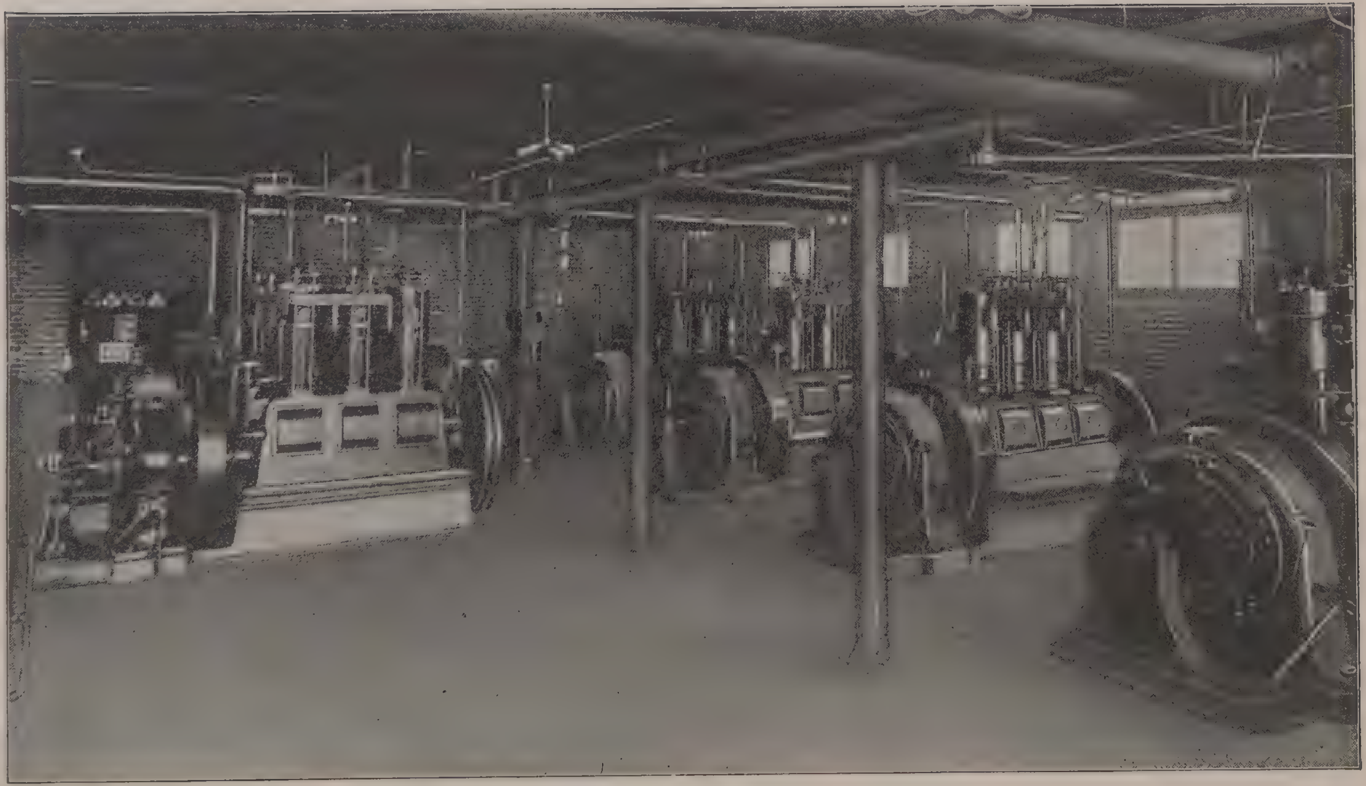


Fig. 17.

The electric burglar alarm furnishes a very efficient protection and is an application of the principles already described. The circuit, instead of being completed by a push, is completed by contacts placed on the doors or windows so that the opening of either will cause the bell to ring. The same device may be used on money-drawers, safes, etc.

In the case of the electric fire alarm, the signal may be given either automatically when the temperature reaches a certain degree, or pushes may be placed in convenient locations to be operated manually. The pushes should be protected by glass so that they will not be tampered with, it being necessary to break the glass to give the alarm.



WALRATH GAS ENGINES DIRECT CONNECTED TO GENERATORS
In Diamond Light & Power Company's Plant, Pittsburg

ELECTRIC LIGHTING.

HISTORY AND DEVELOPMENT.

The history of electric lighting as a commercial proposition begins with the invention of the Gramme dynamo (by Z. J. Gramme) in 1870, together with the introduction of the Jablochkoff candle or light, which was first announced to the public in 1876, and which formed a feature of the International Exposition at Paris in 1878. Up to this time, the electric light was known to but few investigators, one of the earliest being Sir Humphrey Davy who, in 1810, produced the first arc of any great magnitude. It was then called the "voltaic arc", and resulted from the use of two wood charcoal pencils as electrodes and a powerful battery of voltaic cells as a source of current.

From 1840 to 1859, many patents were taken out on arc lamps, most of them operated by clockwork, but these were not successful, due chiefly to the lack of a suitable source of current, since all depended on primary cells for their power. The interest in this form of light died down about 1859, and nothing further was attempted until the advent of the Gramme dynamo.

The incandescent lamp was but a piece of laboratory apparatus up to 1878, at which time Edison produced a lamp using a platinum spiral in a vacuum, as a source of light, the platinum being rendered incandescent by the passage of an electric current through it. The first successful carbon filament was made in 1879, this filament being formed from strips of bamboo. The names of Edison and Swan are intimately connected with these early experiments.

From this time on, the development of electric lighting has been very rapid, and the consumption of incandescent lamps alone has reached several millions each year. When we compare the small amount of lighting done by means of electricity twenty-five years ago with the enormous extent of lighting systems and the numerous applications of electric illumination as they are today, the growth and development of the art is seen to be very great, and the value of a study of this subject may be readily appreciated. While in many cases electricity is not the cheapest source of power for illumination, its admirable qualities and convenience of operation make it by far the most desirable.

Classification. The subject of Electric Lighting may be classified as follows:

1. The type of lamps used.
2. The methods of distributing power to the lamps.
3. The use made of the light, or its application.
4. Photometry and lamp testing.

Taking up these branches in the order named, we may further subdivide the types of lamps used into:

1. Incandescent lamps.
2. Arc lamps.
3. Special lamps, or lamps which do not require carbon, such as the Nernst lamp, Cooper-Hewitt lamp, etc.

The Incandescent Lamp. The incandescent lamp is by far the most common type of lamp used, and the principle of its operation is as follows:

If a current I is sent through a conductor whose resistance is R, for a time t, the conductor is heated, and the amount of heat generated is:

Heat generated $= I^2R\,t$, $I^2R\,t$ representing joules or watt-seconds.

If the current, material, and conditions are so chosen that the substance may be heated in this way until it gives out light, becomes incandescent, and does not deteriorate too rapidly, we have an incandescent lamp. Carbon is the substance chosen for this conductor and for ordinary lamps it is formed into a small thread or filament. Carbon is selected for two reasons:

1. The material must be capable of standing a very high temperature, 1280 to 1330° C.

2. It must be a conductor of electricity with a fairly high resistance.

Platinum has been used for the material, but, as we shall see, its temperature cannot be maintained at a value high enough to make the lamp as efficient as when carbon is used. Nearly all attempts to substitute another substance in place of carbon have failed, and the few lamps which are partially successful will be treated under the head of special lamps. The nature of the carbon employed in incandescent lamps has, however, been much improved over the first forms, and the method of manufacture will be treated next.

MANUFACTURE OF INCANDESCENT LAMPS.

Preparation of the Filament. Cellulose, a chemical compound rich in carbon, is prepared by treating absorbent cotton with zinc chloride in proper proportions to form a uniform, gelatine-like mass. It is customary to stir this under a partial vacuum in order to remove bubbles of air which might be contained in it and destroy its uniformity. This material is then forced, "squirted," through steel dies into alcohol, the alcohol serving to harden the soft, transparent threads. These threads are then thoroughly washed to remove all trace of the zinc chloride, dried, cut to the desired lengths, wound on forms, and carbonized by heating to a high temperature away from air. During carbonization, the cellulose is transformed into pure carbon, the volatile matter being driven off by the high temperature to which the filaments are subjected. The material becomes hard and stiff, assuming a permanent form, shrinking in both length and diameter; the form being specially constructed so as to allow for this shrinkage. The forms are made of carbon blocks which are placed in plumbago crucibles and packed with powdered carbon; the crucibles are covered with loosely fitting carbon covers. The crucibles are gradually brought to a white heat, at which temperature the cellulose is changed to carbon, and then allowed to cool. After cooling, the filaments are removed, measured and inspected, and the few defective ones discarded.

In the early days, these filaments were made of cardboard or bamboo, and later of thread treated with sulphuric acid.

A few of the shapes of filaments now in use are shown in Fig. 1, the different shapes giving a slightly different distribution of light. The shapes here shown are designated as follows: A, U-shaped; B, single-curl; C, single-curl anchored; D, double-loop; E, double-curl; F, double-curl anchored.

Mounting the Filament. After carbonization, the filaments are mounted or joined to wires leading into the globe or bulb. These wires are made of platinum—platinum being the only substance, so far as known, that expands and contracts the same as glass with change in temperature and which, at the same time, will not be melted by the heat developed in the carbon. Since the bulb must remain air-tight, a substance expanding at a different rate from the glass cannot be used. Several methods of fastening the filament to the "leading in" wires have been used, such as forming a socket in the end of the wire, inserting the filament and then squeezing the socket tightly against the carbon, and the use of tiny bolts when cardboard filaments were used, but the pasted joint is now used almost exclusively. Finely powdered carbon is mixed with some adhesive compound, such as molasses, and this mixture is used as a paste for fastening the carbon to the platinum. Later, when current is sent through the joint, the volatile matter is driven off and only the carbon remains. This makes a cheap and, at the same time, a very efficient joint.

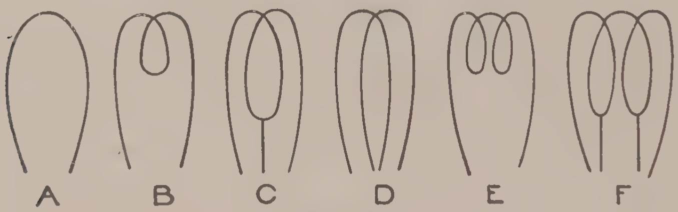


Fig. 1.

Flashing. Filaments, prepared and mounted in the manner just described, are fairly uniform in resistance, but it has been found that their quality may be much improved and their resistance very closely regulated by depositing a layer of carbon on the outside of the filament by the process of "flashing". By flashing is meant heating the filament to a high temperature when immersed in a hydrocarbon gas, such as gasoline vapor, under partial vacuum. Current is passed through the filament in this process to accomplish the heating. Gas is used, rather than a liquid, to prevent too heavy a deposit of the carbon. Coal gas is not recommended because the carbon, when deposited from this, has a dull black appearance. The effects of flashing are as follows:

1. The diameter of the filament is increased by the deposited carbon and hence its resistance is decreased. The process must be discontinued when the desired resistance is reached. Any little irregularities in the filament will be eliminated since the smaller sections, having the greater resistance, will become hotter than the remainder of the filament and the carbon is deposited more rapidly at these points.

2. The character of the surface is changed from a dull black and comparatively soft nature to a bright gray coating which is much harder and which increases the life and efficiency of the filament.

Exhausting. After flashing, the filament is sealed in the bulb and the air exhausted through the tube A in Fig. 2, which shows the lamp in different stages of its manufacture. The exhaustion is accomplished by means of mechanical air pumps, supplemented by Sprengle or mercury pumps and chemicals. Since the degree of exhaustion must be high, the bulb should be heated during the process so as to drive off any gas which may cling to the glass. When chemicals are used, as is now almost universally the case, the chemical is placed in the tube A and, when heated, serves to take up much of the remaining gas. Exhaustion is necessary for several reasons:

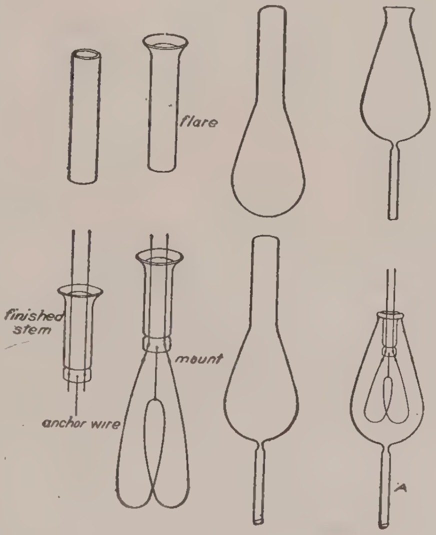


Fig. 2.

1. To avoid oxidization of the filament.
2. To reduce the heat conveyed to the globe.
3. To prevent wear on the filament due to currents or eddies in the gas.

After exhausting, the tube A is sealed off and the lamp completed for testing by attaching the base by means of plaster of Paris. Fig. 3 shows some of the forms of completed incandescent lamps.

Voltage and Candle-Power. Incandescent lamps vary in size from the miniature battery and candelabra lamps to those of several hundred candle-power, though the latter are very seldom used. The more common values for the candle power are 8, 16, 25, 32, and 50, the choice of candle-power depending on the use to be made of the lamp.

The voltage will vary depending on the method of distribution of the power. For what is known as parallel distribution, 110 or 220 volts are generally used. For the higher values of the voltage, long and slender filaments must be used, if the candle-power is to be low, and lamps of less than 16 candle-power for 220-volt circuits are not practical, owing to difficulty in manufacture. For series distribution, a low voltage and higher current is used, hence the filaments may be quite heavy. Battery lamps operate on from 4 to 24 volts, but the vast majority of lamps for general illumination are operated at or about 110 volts.

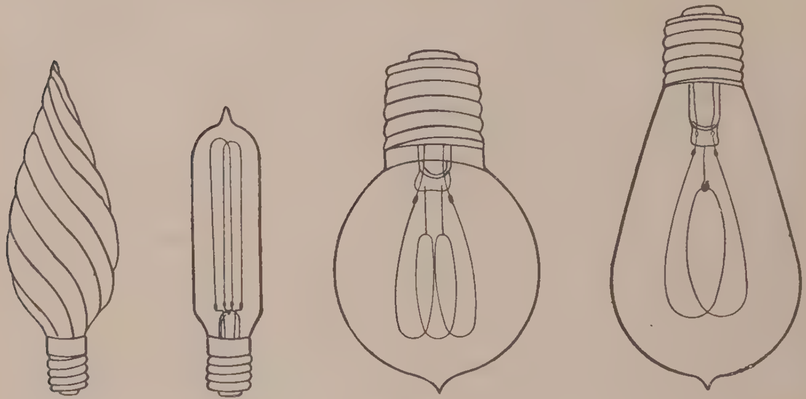
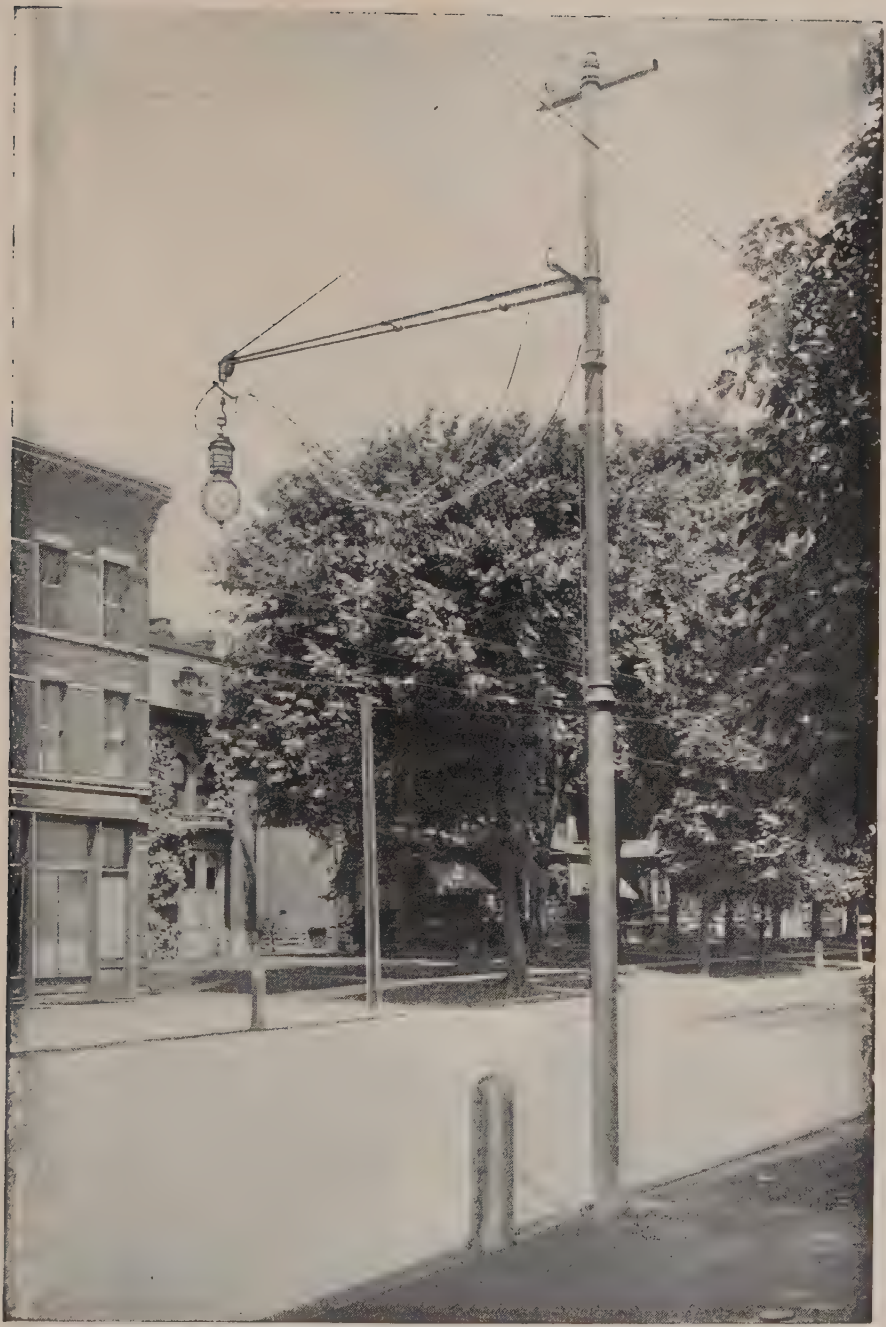


Fig. 3.

Efficiency. By the efficiency of an incandescent lamp is meant the power required at the lamp terminals per candle-power of light given. Thus, if a lamp giving an average horizontal candle-power of 16 consumes $\frac{1}{2}$ an ampere at 112 volts, the total number of watts consumed will be $112 \times \frac{1}{2} = 56$, and the watts per candle-power will be $56 \div 16 = 3.5$. The efficiency of such a lamp is said to be 3.5 watts per candle-power. "Watts economy" is sometimes used for "efficiency".



MAST SUSPENSION OF ARC LAMPS.

General Electric Company.

The efficiency of a lamp depends on the temperature at which the filament is run. This temperature is between 1280° and 1330° C, and the curve in Fig. 4 shows the increase of efficiency with the increase of temperature. The temperature attained by a filament depends on the rate at which heat is radiated and the amount of power supplied. The rate of radiation of heat is proportional to the area of the filament, the elevation in temperature, and the emissivity of the surface.

By emissivity is meant the number of heat units emitted from unit surface per degree rise in temperature above that of surrounding bodies. The bright surface of a flashed filament has a lower emissivity than the dull surface of an unheated filament, hence less energy is lost in heat radiation and the efficiency of the filament is increased.

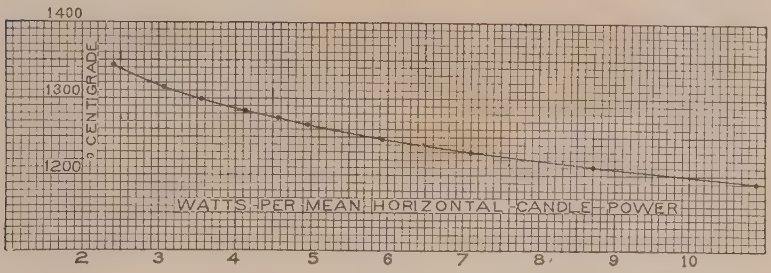


Fig. 4.

As soon as incandescence is reached, the illumination increases much more rapidly than the emission of heat, hence the increase in efficiency shown in Fig. 4. Were it not for the rapid disintegration of the carbon at high temperature, an efficiency higher than 3.1 watts could be obtained.

Relation of Life to Efficiency. By the useful life of a lamp is meant the length of time a lamp will burn before its candle-power has decreased to such a value that it would be more economical to replace the lamp with a new one than to continue to use it at its decreased value. A decrease to 80% of the initial candle-power is now taken as the point at which a lamp should be replaced, and the normal life of a lamp is in the neighborhood of 800 hours. To obtain the most economical results, lamps should always be replaced at the end of their useful life.

In Table 1 are given values of the efficiency and life of a 3.5-watt, 110-volt lamp for various voltages impressed on the lamp. These values are plotted in Fig. 5. These curves show that a 3% increase of voltage on the lamp reduces the life by one-half, while an increase of 6% causes the useful life to fall to one-third its normal value. The effect is even greater when 3.1-watt lamps are used, but not so great with 4-watt lamps. From this we see that the regulation of the voltage used on the system must be very good if high efficiency lamps are to be used, and this regulation will determine the type of lamp to be installed.

Selection of Lamps. Lamps taking 3.1 watts per candle-power will give satisfaction only when the regulation of voltage is the best—practically a constant voltage maintained at the normal voltage of the lamp.

TABLE I.

Effects of Change in Voltage.

Standard 3.5 Watt Lamp.

Voltage Per Cent. of Normal.	Candle-Power Per Cent. of Normal.	Watts Per Candle-Power.	Life Per Cent. of Normal.	Deterioration Per Cent. of Normal
90	53	5.36		
91	56	5.09		
92	61	4.85		
93	65	4.63		
94	69	4.44	394	25
95	73	4.26	310	32
96	78	4.09	247	44
97	83	3.93	195	51
98	88	3.78	153	65
99	94	3.64	126	79
100	100	3.5	100	100
101	106	3.38	84	118
102	111	3.27	68	146
103	116	3.16	58	173
104	123	3.05	47	211
105	129	2.95	39	253
106	137	2.85	31	316
107	143	2.76	26	380
108	152	2.68	21	474
109	159	2.60	17	575
110	167	2.53	16	637

Lamps of 3.5 watts per candle-power should be used when the regulation is fair, say with a maximum variation of 2% from the normal voltage.

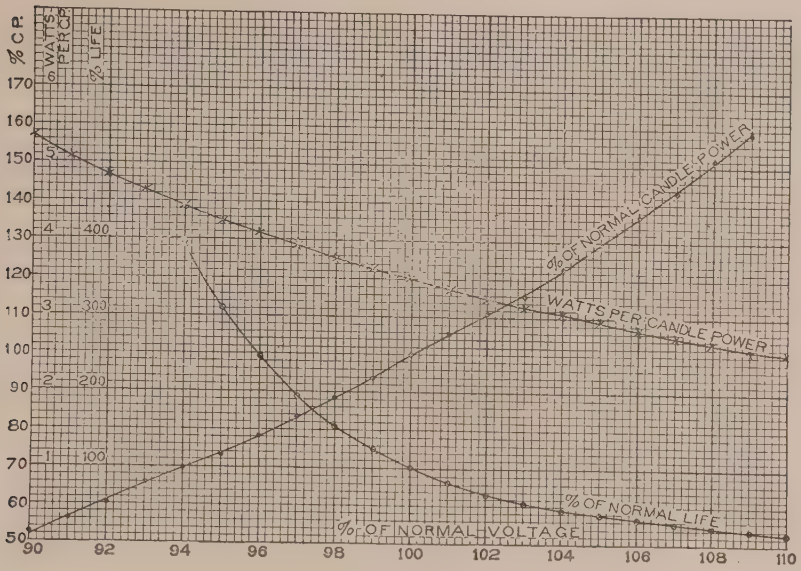


Fig. 5.

Lamps of 4 watts per candle-power should be installed when the regulation is poor. These values are for 110-volt lamps. A 220-volt lamp should have a lower efficiency to give a long life.

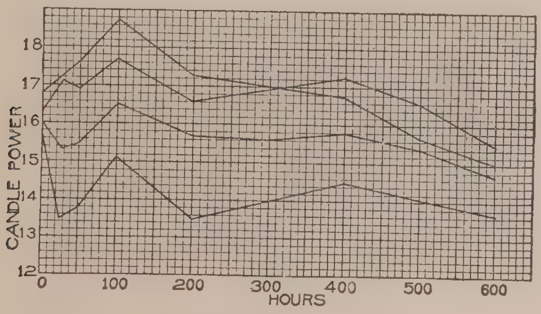


Fig. 6.

Lamps should always be renewed at the end of their useful life, this point being termed the "smashing-point", as it is cheaper to replace the lamp than to run it at the reduced candle-power. Some recommend running these lamps at a higher voltage, but that means at a reduced efficiency, and it is not good practice to do this.

Fig. 6 shows the life curves of a series of incandescent lamps. These curves show that there is an increase in the candle-power of some of the lamps during the first 100 hours, followed by a period during which the value is fairly constant, after which the light given by the lamp is gradually reduced to about 80% of the initial candle-power.

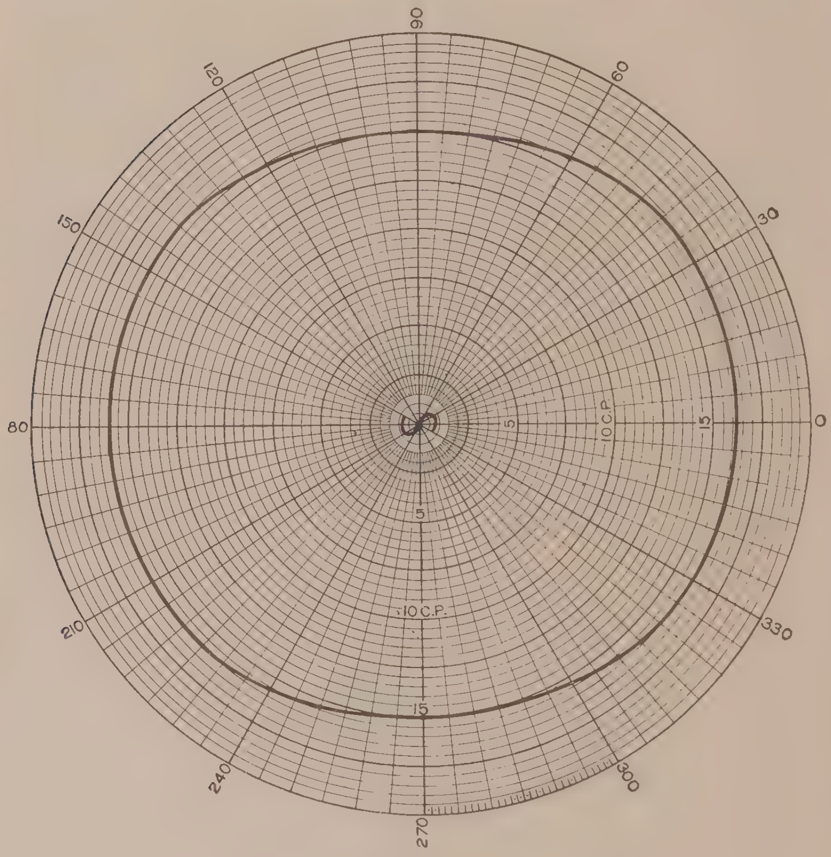


Fig. 7.

DISTRIBUTION OF LIGHT.

In Fig. 1 are shown various forms of filaments used in incandescent lamps, and Figs. 7 and 8 show the distribution of light from a single-loop filament of cylindrical cross-section.

Fig. 7 shows the distribution of light in a horizontal plane, the lamp being mounted in a vertical position, and Fig. 8 shows the distribution in a vertical plane. By changing the shape of the filament, the light distribution is varied. A mean of the readings taken in the horizontal plane forms the *mean horizontal candle-power*, and this candle-power rating is the one generally assumed for the ordinary incandescent lamp. A mean of the readings taken in a vertical plane gives us the mean vertical candle-power, but this value is of little use.

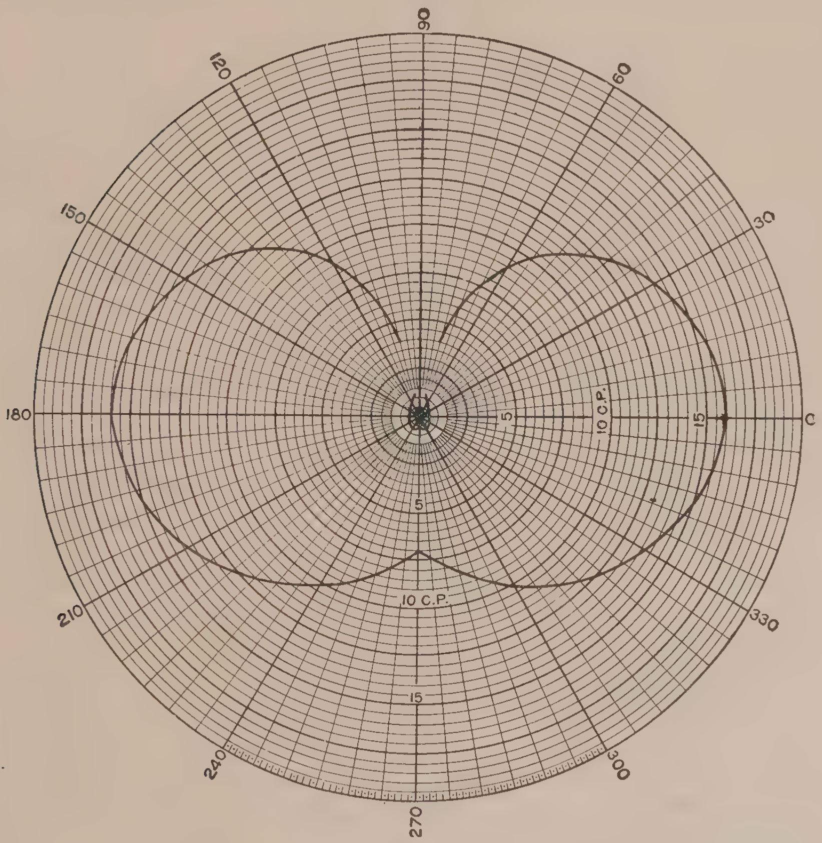


Fig. 8.

Mean Spherical Candle-Power. When comparing lamps which give an entirely different light distribution, the mean horizontal candle-power does not form a proper basis for such comparison, and the mean spherical or the mean hemispherical candle-power is used instead. By mean spherical candle-power is meant a mean value of the light taken in all directions. The methods for determining this will be taken up under *photometry*. The mean hemispherical candle-power has reference, usually, to the light given out below the horizontal plane.

ARC LAMPS.

The Electric Arc. Suppose two carbon rods are connected in an electric circuit, and the circuit closed by touching the tips of these rods together; on separating the carbons again the circuit will not be broken, provided the space between the carbons be not too great, but will be maintained through the arc formed at these points. This phenomenon, which is the basis of the arc light, was first observed on a large scale by Sir Humphrey Davy, who used a battery of 2,000 cells and produced an arc between charcoal points four inches apart.

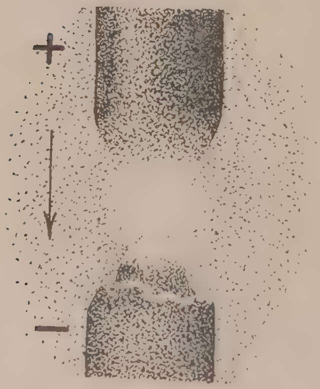


Fig. 9.

As the incandescence of the carbons across which an arc is maintained, together with the arc itself, forms the source of light for all arc lamps, it will be well to study the nature of the arc. Fig. 9 shows the general appearance of an arc between two carbon electrodes when maintained by direct current.

Here the current is assumed as passing from the top carbon to the bottom one as indicated by the arrow and signs. We find, in the direct-current arc, that the most of the light issues from the tip of the positive carbon, or electrode, and this portion is known as the *crater* of the arc. This crater has a temperature of from 3,000 to 3,500° C, the temperature at which the carbon vaporizes, and gives fully 80 to 85% of the light furnished by the arc. The negative carbon becomes pointed at the same time that the positive one is hollowed out to form the crater, and it is also incandescent but not to as great a degree as the positive carbon.

Between the electrodes there is a band of violet light, the arc proper, and this is surrounded by a luminous zone of a golden yellow color. The arc proper does not furnish more than 5% of the light emitted.

The carbons are worn away or consumed by the passage of the current, the positive carbon being consumed about twice as rapidly as the negative.

The light distribution curve of a *direct-current arc*, taken in a vertical plane, is shown in Fig. 10. Here it is seen that the maximum amount of light is given off at an angle of about 50° from the vertical, the negative carbon shutting off the rays of light that are thrown directly downward from the crater.

If alternating current is used, the upper carbon becomes positive and negative alternately, and there is no chance for a crater to be formed, both carbons giving off the same amount of light and being consumed at about the same rate. The light distribution curve of an *alternating-current arc* is shown in Fig. 11.

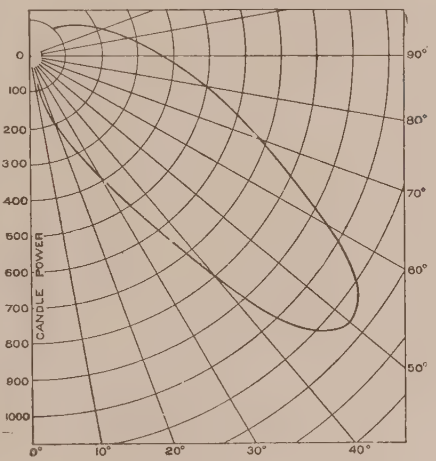


Fig. 10.

Arc Lamp Mechanisms. In a practical lamp we must have not only a pair of carbons for producing the arc, but also means for supporting these carbons, together with suitable arrangements for leading the current to them and for maintaining them at the proper distance apart. The carbons are kept separated the proper distance by the operating mechanisms which must perform the following functions:

1. The carbons must be in contact, or be brought into contact, to start the arc when the current first flows.
2. They must be separated at the right distance to form a proper arc immediately afterward.
3. The carbons must be fed to the arc as they are consumed.
4. The circuit should be open or closed when the carbons are entirely consumed, depending on the method of power distribution.

The feeding of the carbons may be done by hand, as is the case in some stereopticons using an arc, but for ordinary illumination the striking and maintaining of the arc must be automatic. It is made so in all cases by means of solenoids acting against the force of gravity or against springs. There are an endless number of such mechanisms, but a few only will be described here. They may be roughly divided into three classes:

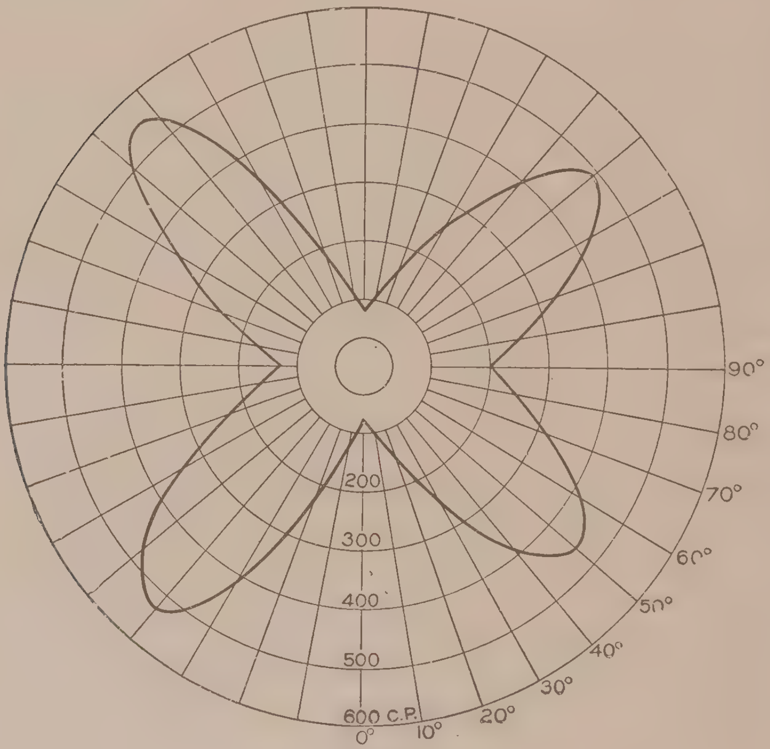


Fig. 11.

1. Shunt Mechanisms.
2. Series Mechanisms.
3. Differential Mechanisms.

In **Shunt Lamps**, the carbons are held apart before the current is turned on, and the circuit is closed through a solenoid connected in across the gap so formed. All of the current must pass through this coil at first, and the plunger of the solenoid is arranged to draw the carbons together, thus starting the arc. The pull of the solenoid and that of the springs are adjusted to maintain the arc at its proper length.

Such lamps have the disadvantage of a high resistance at the start—450 ohms or more—and are difficult to start on series circuits, due to the high voltage required. They tend to maintain a constant voltage at the arc, but do not aid the dynamo in its regulation, so that the arcs are liable to be a little unsteady.

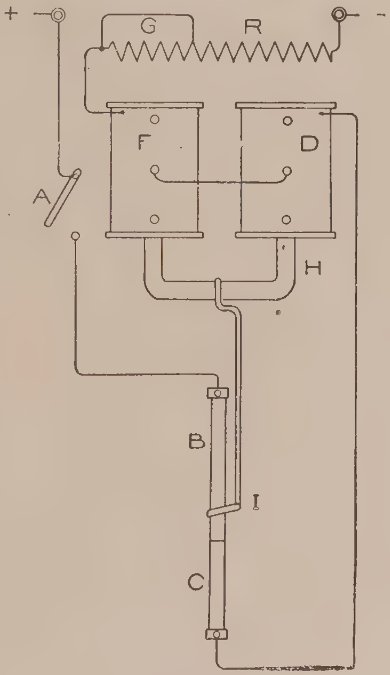


Fig. 12.

With the **Series-Lamp Mechanism**, the carbons are together when the lamp is first started and the current, flowing in the series coil, separates the electrodes, striking the arc. When the arc is too long, the resistance is increased and the current lowered so that the pull of the solenoid is weakened and the carbons feed together. This type of lamp can be used only on constant-potential systems.

Fig. 12 shows a diagram of the connection of such a lamp. This diagram is illustrative of the connection of one of the lamps manufactured by the Western Electric Company, for use with direct current on a constant-potential system. The symbols + and — refer to the terminals of the lamp, and the lamp must be so connected that the current flows from the top carbon to the bottom one. R is a series resistance, adjustable for different voltages by means of the shunt G. F and D are the controlling solenoids connected in series with the arc. B and C are the positive and negative carbons respectively, while A is the switch for turning the current on and off. H is the plunger of the solenoids and I the carbon clutch, this being what is known as a "carbon feed" lamp. The carbons are together when A is first closed, the current is excessive, and the plunger is drawn up into the solenoids, lifting the carbon B until the resistance of the arc lowers the current to such a value that the pull of the solenoid just counterbalances the weight of the plunger and carbon. G must be so adjusted that this point is reached when the arc is at its normal length.

In the **Differential Lamp**, the series and shunt mechanisms are combined, the carbons being together at the start, and the series coil arranged so as to separate them while the shunt coil is connected across the arc, as before, to prevent the carbons from being drawn too far apart. This lamp operates only over a low-current range, but it tends to aid the generator in its regulation.

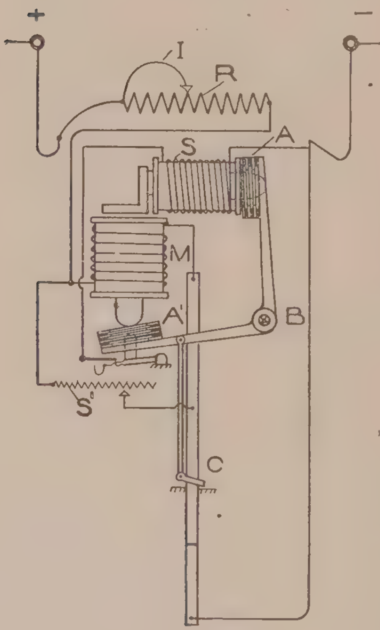


Fig. 13.

Fig. 13 shows a lamp having a differential control, this also being the diagram of a Western Electric Company arc lamp for direct-current, constant-potential system. Here S represents the shunt coil and M the series coil, the armature of the two magnets A and A′ being attached to a bell-crank, pivoted at B, and attached to the carbon clutch C. The pull of coil S tends to lower the carbon while that of M raises the carbon, and the two are so adjusted that equilibrium is reached when the arc is of the proper length. All of the lamps are fitted with an air dashpot or some damping device to prevent too rapid movements of the working parts.

The methods of supporting the carbons and feeding them to the arc may be divided into two classes:

1. Rod feed.
2. Carbon feed.

Lamps using a **Rod Feed** have the upper carbons supported by a conducting rod, and the regulating mechanism acts on this rod, the current being fed to the rod by means of a sliding contact. Fig. 14 shows the arrangement of this type of feed. The rod is shown at R, the sliding contact at B, and the carbon is attached to the rod at C.

These lamps have the advantage that carbons, which do not have a uniform cross-section or smooth exterior, may be used, but they possess the disadvantage of being very long in order to accommodate the rod. The rod must also be kept clean so as to make a good contact with the brush.

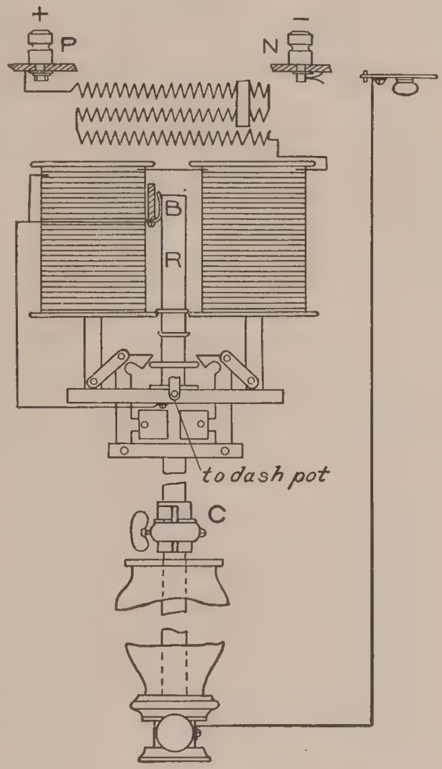


Fig. 14.

In **Carbon-Feed** lamps the controlling mechanism acts on the carbons directly through some form of clutch such as is shown at C in Fig. 15. This clamp grips the carbon when it is lifted, but allows the carbon to slip through it when the tension is released. For this type of feed the carbon must be straight and have a uniform cross-section as well as a smooth exterior. The current may be led to the carbon by means of a flexible lead and a short carbon holder.

Double-Carbon Lamps. In order to increase the life of the early form of arc lamp without using too long a carbon, the double-carbon type was introduced. This type uses two sets of carbons, both sets being fed by one mechanism so arranged that when one pair of the electrodes is consumed the other is put into service. With the introduction of the enclosed arcs, this form of lamp is rapidly disappearing, although a few are still in use.

Arc lamps are constructed to operate on *Direct Current* or *Alternating Current* systems when connected in *Series* or in *Multiple*. They are also made in both the *Open* and the *Enclosed* forms, but almost all of the lamps operating on alternating current or on constant-potential, direct current are enclosed.

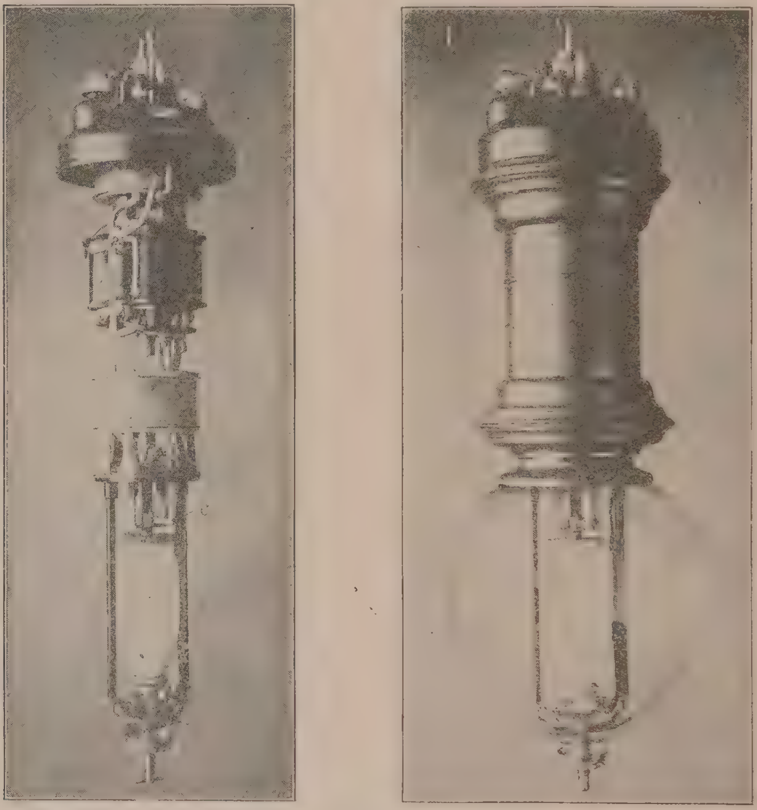


Fig. 15.

By an *Open Arc* is meant an arc lamp in which the arc is exposed to the atmosphere, while in the *Enclosed Arc* an inner or enclosing globe surrounds the arc, and this globe is covered with a cap which renders it nearly air-tight. Fig. 15 is a good example of an enclosed arc as manufactured by the General Electric Company.

Open Arcs for direct-current systems were the first to be used to any great extent, and they are used considerably at present, although they are being rapidly replaced by the enclosed types or the alternating-current systems. They are always connected in series, and are run from some form of special arc machine, a description of which may be found in "Types of Dynamo Electric Machinery".

Each lamp requires in the neighborhood of 50 volts for its operation, and, since the lamps are connected in series, the voltage of the system will depend on the number of lamps; therefore, the number of lamps that may be connected to one machine is limited by the maximum allowable voltage on that machine. By special construction as many as 125 lamps are run from one machine, but even this size of generator is not so efficient as one of greater capacity. Such generators are usually wound for 6.6 or 9.6 amperes. Since the carbons are exposed to the air at the arc, they are rapidly consumed, requiring that they be renewed daily for this type of lamp.

Enclosed Direct-Current Arc Lamps for series systems are constructed much the same as the open lamp, and are controlled by either shunt or differential mechanism. They require a voltage from 68 to 75 at the arc, and are usually constructed for from 5 to 6.8 amperes. They also require a constant-current generator.

Arc Lamps for Constant-Potential direct-current systems must have some resistance connected in series with them to keep the voltage at the arc at its proper value. This resistance is made adjustable so that the lamps may be used on any circuit. Its location is clearly shown in Fig. 15, one coil being located above, the other below the operating solenoids.

Arc Lamps for Alternating Currents do not differ greatly in construction from the direct-current arcs. When iron or other metal parts are used in the controlling mechanism, they must be laminated or so constructed as to keep down induced or eddy currents which might be set up in them. For this reason the metal spools, on which the solenoids are wound, are slotted at some point to prevent them from forming a closed secondary to the primary formed by the solenoid winding. On constant potential circuits a reactive coil is used in place of a part of the resistance for cutting down the voltage at the arc.

Interchangeable Arc Lamps are manufactured which may be readily adjusted so as to operate on either direct or alternating current, and on voltages from 110 to 220. Two lamps may be run in series on 220-volt circuits.

The distribution of light, and the resulting illumination for the different lamps just considered, will be taken up later. Aside from the distribution and quality of light, the enclosed arc has the advantage that the carbons are not consumed so rapidly as in the open lamp because the oxygen is soon exhausted from the inner globe and the combustion of the carbon is greatly decreased. They will burn from 80 to 100 hours without re-trimming.

TABLE 2.

		Watts Consumed.					Mean Intensity in H. U.			Mean Watts.		
							Spherical.		Lower Hemi-spherical	Spherical H. U.		Lower Hemi-spherical
D. C. Lamp.	Current.	In Lamp.		In Arc.		Mechanism.	Op. Outer.	Clear Outer	Clear Outer.	Op. Outer.	Clear Outer.	Clear Outer.
								235	332		2.37	1.66
1	5.01	551		401		150	172	256*	362*	3.10	2.18*	1.52*
3	5.08	559		406		252	195	216	282	2.85	2.60	1.99
4	4.76	524		381		143	127	139	208	4.12	3.76	2.52
5	4.16†	458		333		125	154	174	221	2.96	2.63	2.07
7	4.76	524		381		143	203	333	317	2.63	2.20	1.65
9	4.84	532		387		145	182	226	281	2.83	2.38	1.89
10	4.99	549		399		150	202	242	309	2.74	2.24	1.77
12	4.87	536		390		146	178	195	230	3.05	2.66	2.33
Mean	4.9	529		384		144	176	207	272	3.03	2.60	1.98
A. C. Lamp.	Current.	In Lamp.	Power Factor Lamp.	In Arc.	Power Factor Arc.	Mechanism.						
101	6.40	448	.63	340	.82	108	127	141	206	3.52	3.17	2.17
								203	236		2.26	1.91
102	6.79	459	.61	375	.73	84	146	176†	226†	3.31	2.60†	1.72†
103	5.89	424	.65	344	.75	80	116	130	147	3.66	3.15	2.8[illegible]
105	6.20	414	.61	382	.80	32	128	187	219	3.24	2.20	1.89
								153	169		2.56	2.23
106	6.12	378	.56	298	.70	80	132	182†	284	2.82	2.19†	1.48†
108	6.48	457	.64	383	.80	74.5	133	175	211	3.20	2.61	2.16
110	6.18	339	.49	276	.72	63	140*	126	143	2.41*	2.68	2.37
Mean	6.29	417	.60	342	.76	74.5	130	159	190	3.31	2.66	2.23

*Condition of no outer globe. †Condition with shade on lamp. H. U Hefner Units.

Rating of Arc Lamps. Open arcs have been classified as follows:

Full Arcs, 2,000 candle-power taking 9.5 to 10 amps. or 450–480 watts.
Half Arcs, 1,200 candle-power taking 6.5 to 7 amps. or 325–350 watts.

These candle-power ratings are much too high, and run more nearly 1,200 and 700, respectively, for the point of maximum intensity and less than this if the mean spherical candle-power be taken. For this reason, the ampere or watt rating is now used to indicate the power of the lamp. Enclosed arcs use from 3 to 6.5 amperes, but the voltage at the arc is higher than for the open lamp. Table 2 gives some data on enclosed arcs on constant-potential circuits.

Efficiency. The efficiency of arc lamps is given as follows:

Direct Current Arc (enclosed) 2.9 watts per candle-power.
Alternating Current Arc (enclosed) 2.95 watts per candle-power.
Direct Current Arc (open) .6–1.25 watts per candle-power.

Arc-Lamp Carbons are either moulded or forced from a product known as petroleum coke or from similar materials such as lampblack. The material is thoroughly dried by heating to a high temperature, then ground to a fine powder and combined with some substance such as pitch which binds the fine particles of carbon together. After this mixture is again ground it is ready for moulding. The powder is put in steel moulds and heated until it takes the form of a paste, when the necessary pressure is applied to the moulds. For the forced carbons, the powder is formed into cylinders which are placed in machines which force the material through a die so arranged as to give the desired diameter. The forced carbons are often made with a core of some special material, this core being added after the carbon proper has been finished. The carbons, whether moulded or forced, must be carefully baked to drive off all volatile matter. The forced carbon is always more uniform in quality and cross-section, and is the type of carbon which must be used in the carbon feed lamp. The adding of a core of a different material seems to change the quality of light, and being more readily volatilized, keeps the arc from wandering.

Plating of carbons with copper is sometimes resorted to for moulded forms for the purpose of increasing the conductivity, and, by protecting the carbon near the arc, prolonging the life.

SPECIAL LAMPS.

Under this heading may be considered all lamps which do not use carbon as the incandescent material, as well as some lamps

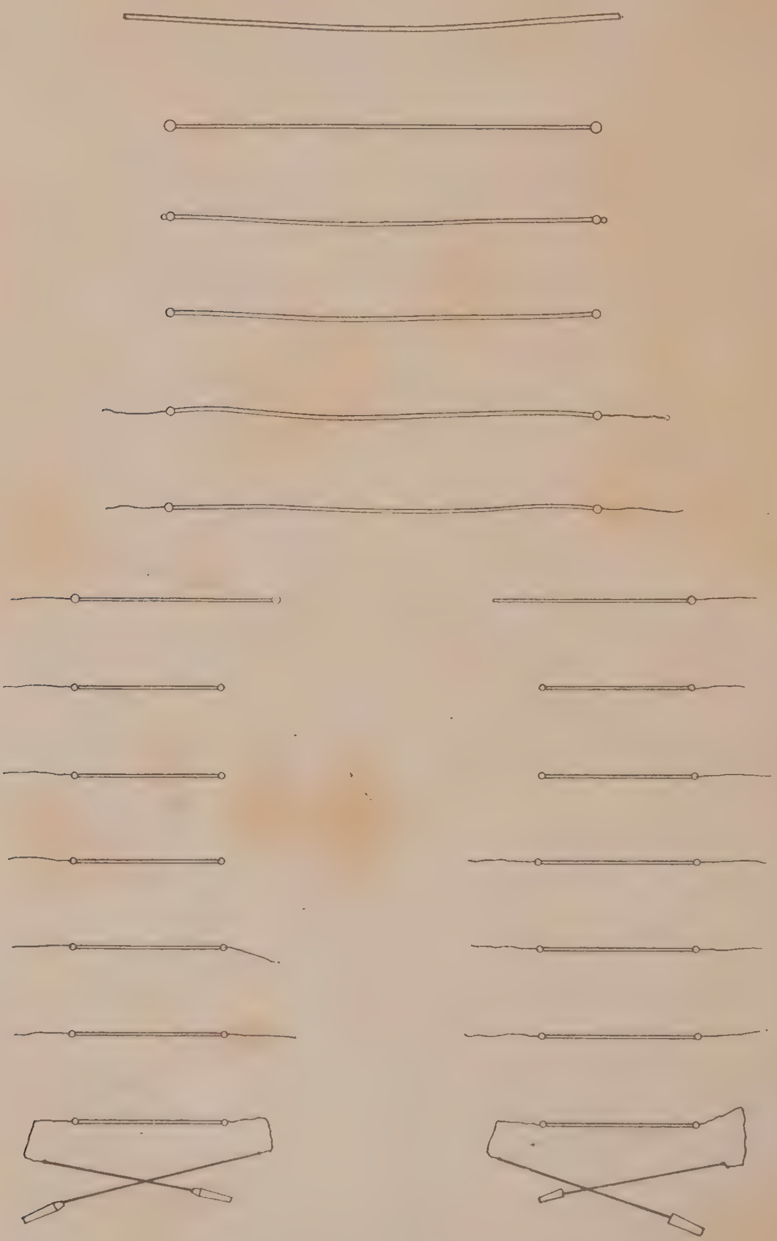
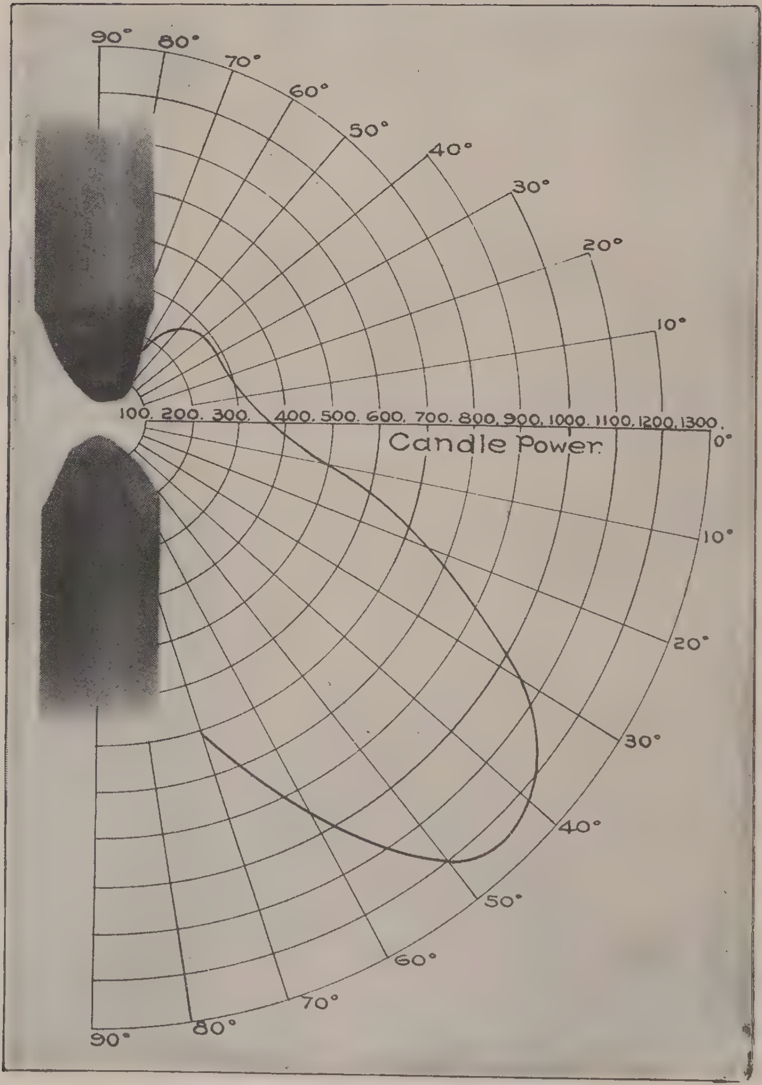


Fig. 16.



DISTRIBUTION CURVE FOR ARC LAMP.

Fort Wayne Electric Works.

which use carbon in conjunction with other materials. The first of these lamps, or the one at present most widely used, is the Nernst Lamp.

The Nernst Lamp is an incandescent lamp using for the incandescent material certain oxides of the rare earths. The oxide is mixed in the form of a paste, then squirted through a die into a string which is subjected to a roasting process forming the filament or *glower* material of the lamp. The glowers are cut the desired length and platinum terminals attached. The attachment of these terminals to the glowers is a very important process in the manufacture of the lamp, and is accomplished by fusing the ends of the glower and the platinum lead into small beads, and, when the two are brought into contact, the platinum is sucked up into the glower head, forming a very neat and efficient connection. Fig. 16 shows several completed glowers.

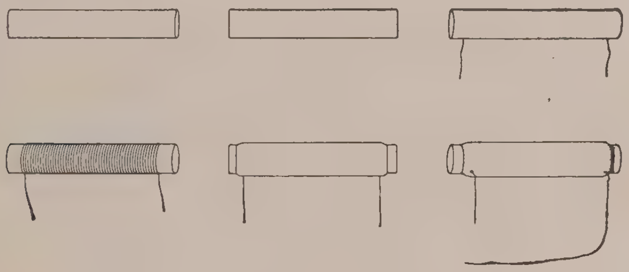


Fig. 17.

As the glower is a non-conductor when cold, some form of *heater* is necessary to bring it up to a temperature at which it will conduct. Two forms of heater are used, the first being formed of fine platinum wire wound over a porcelain tube as a support and covered with porcelain paste to prevent deterioration as much as possible. These "heater tubes", as they are called, are mounted just above the glowers in the finished lamp. The second form of heater is known as the "spiral heater", and this is also made of fine platinum wire wound on a porcelain rod and covered with paste, the rod being then formed on a mandrel to the desired shape. Figs. 17 and 18 show the two forms of heaters.

The heating device is connected across the circuit when the lamp is first turned on, and it must be cut out of circuit automatically when the glower becomes a conductor, otherwise the heater would soon be destroyed. This automatic *cut-out* is operated by means of an electromagnet so arranged that current flows through its coil as soon as the glower conducts and opens a form of silver contact cutting out the heater. The heater circuit is normally kept closed by the force of gravity so that the lamps will operate only in one position. A successful form of universal cut-out, that is, one which will operate when the lamp is in any position, has not yet been put on the market, though experiments with this type are being made.

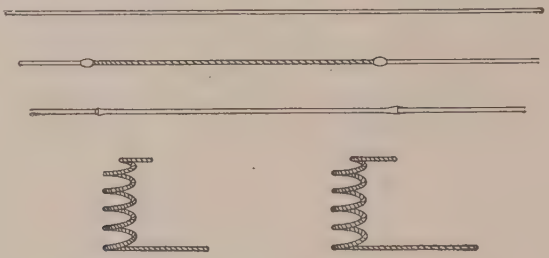


Fig. 18.

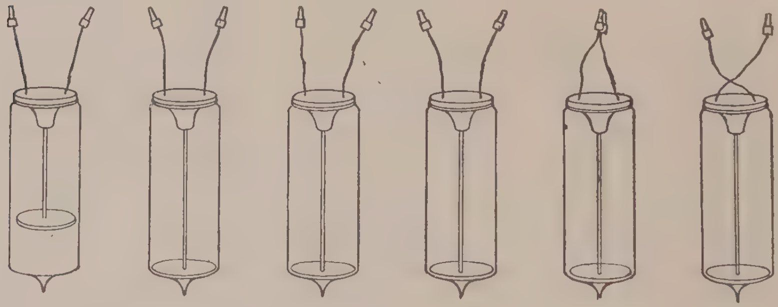


Fig. 19.

The conductivity of the glower increases with its temperature; hence, if used on a constant-potential circuit directly, its temperature would continue to increase, due to the greater current flowing, until the glower was destroyed. To prevent this increase of current, a *ballast resistance* of fine iron wire is connected in series with the glower. As is well known, the resistance of iron wire increases quite rapidly with increase of temperature, and this resistance is so adjusted that the resistance of the combined circuit reaches a constant value when the current is of the proper strength. The iron wire must be protected from the air to prevent oxidization and too rapid temperature changes, and, for this reason, it is mounted in a glass bulb filled with hydrogen. Hydrogen has been selected for this purpose because it is an inert gas and conducts the heat from the ballast to the walls of the bulb better than other gases. Fig. 19 shows the form of bulb which contains the ballast.

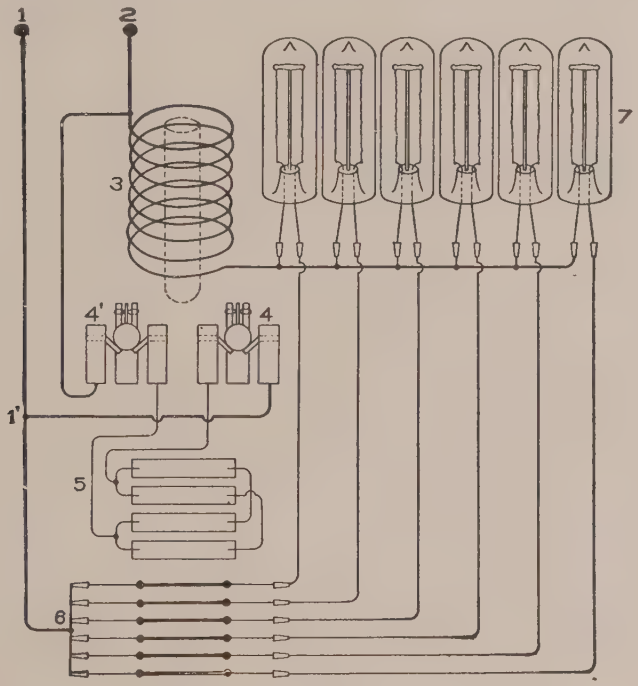


Fig. 20.

All of the parts enumerated, namely, glower, heater, cut-out and ballast, are mounted in a suitable manner, the smaller lamps having but one glower and arranged to fit an incandescent lamp socket, while the larger types have as many as six glowers and are arranged to be supported in a manner similar to arc lamps. All of the parts are interchangeable and may be easily renewed.

Fig. 20 shows the complete connections of a six-glower lamp. Current enters the lamp at terminal 1 (or 2), passes through the

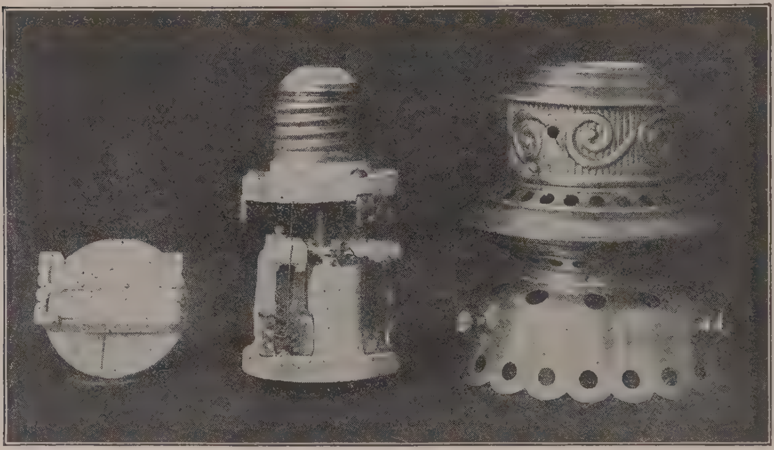


Fig. 21.

contacts of the cut-out 4, to the heater circuit 5, then to the contacts 4′ and to terminal 2. When the glowers become hot enough to conduct, the current divides at 1′, part of it going through the glowers 6, the ballast 7, and the cut-out coil 3 to terminal 2. By the time the current in the glower has reached its normal value, the contacts at 4 and 4′ have opened, cutting out the heater coils

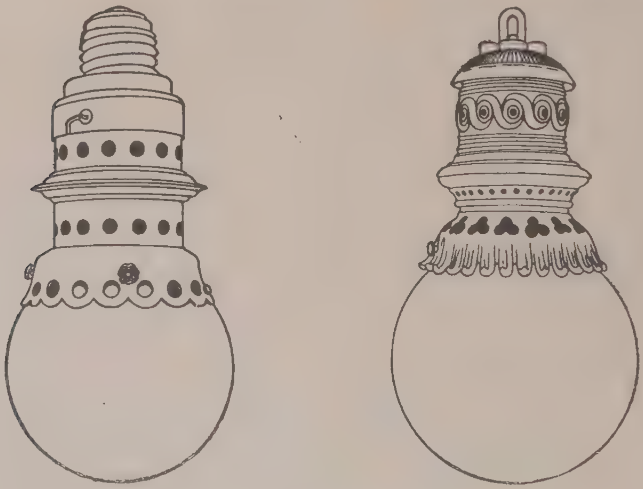


Fig. 23.

entirely. The heaters are so arranged that if one is destroyed, the other two will heat the glowers as quickly as possible.

Fig. 21 shows the parts of a single-glower lamp with the exception of the globe. Fig. 22 illustrates a six-glower street lamp. Fig. 23 shows lamps for inside use completely assembled. Fig. 24 shows a glower and spiral heater so mounted that the two may be very readily replaced. This type is used on some of the very latest forms of lamps put on the market by the Nernst Lamp Company of Pittsburg, which company controls the manufacture of these lamps in the United States.

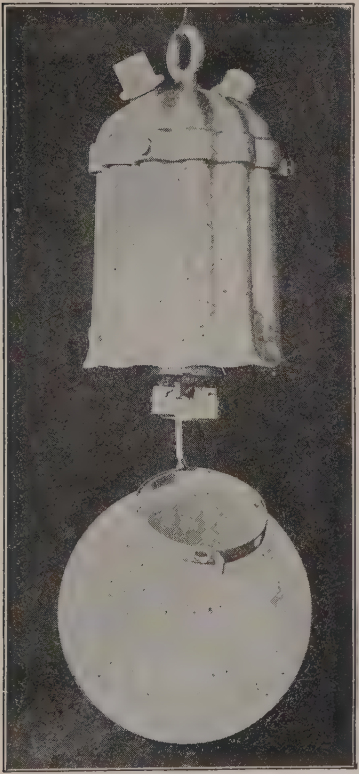


Fig. 22.

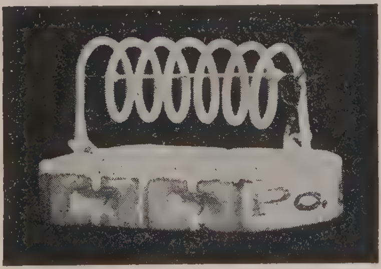


Fig. 24.

This type of lamp is used most extensively on alternating-current circuits at a frequency of about 60 cycles, and preferably at 220 volts, as the efficiency is better at this voltage, due to less energy being consumed in the ballast. Series lamps, and lamps operated on direct current, are now equally successful.

The advantages claimed for the Nernst lamp are increased efficiency, a good color of light, and a good light distribution. The efficiency varies with the type and the voltage used, as well as with the direction in which the candle-power is measured and the type of globe used. For a 100-hour run on a two-glower, 220-volt lamp using a 6-inch light sand-blasted globe, the watts varied from 170 to 158, while the mean hemispherical candle-power varied from 67.8 to 50.8, giving an efficiency from 2.5 to 3.1 watts per mean hemispherical candle-power; showing an efficiency better than the incandescent but not so good as the arc lamp.

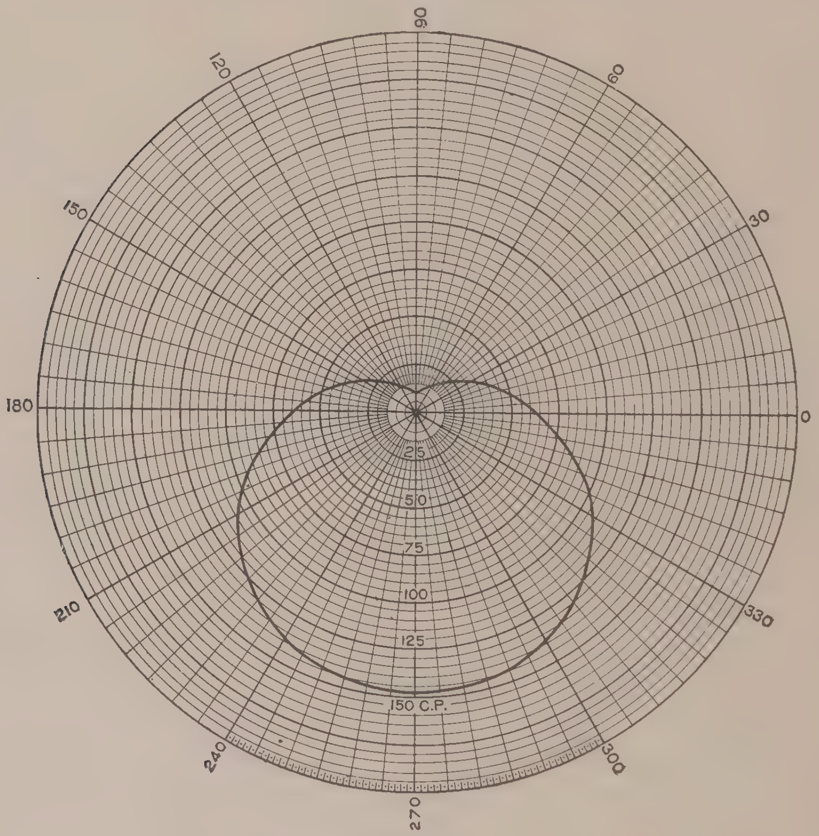


Fig. 25.

Fig. 25 shows two distribution curves for Nernst lamps.

To give the best results, lamps using the tube heaters must be cleaned regularly at the intervals of about 100 hours of burning. The spiral heaters are not cleaned, but are renewed at the end of the useful life of the glower. The light given by these lamps is very white in color, and the use of sand-blasted or alabaster globes reduces its intense brilliancy.

Osmium Lamps. Osmium has been experimented on as a substance to replace carbon in the ordinary incandescent lamp, and so far very efficient lamps have been constructed using this material, but the voltage is low, due to the low resistance of the material and the difficulty of making a filament fine enough to give the desired resistance for higher voltages. At 25 volts, lamps are constructed giving an efficiency of 1.5 to 1.7 watts per candle-power, and with a life comparable with that of a 3.5-watt incandescent lamp. The low voltage makes this lamp undesirable for parallel distribution systems.

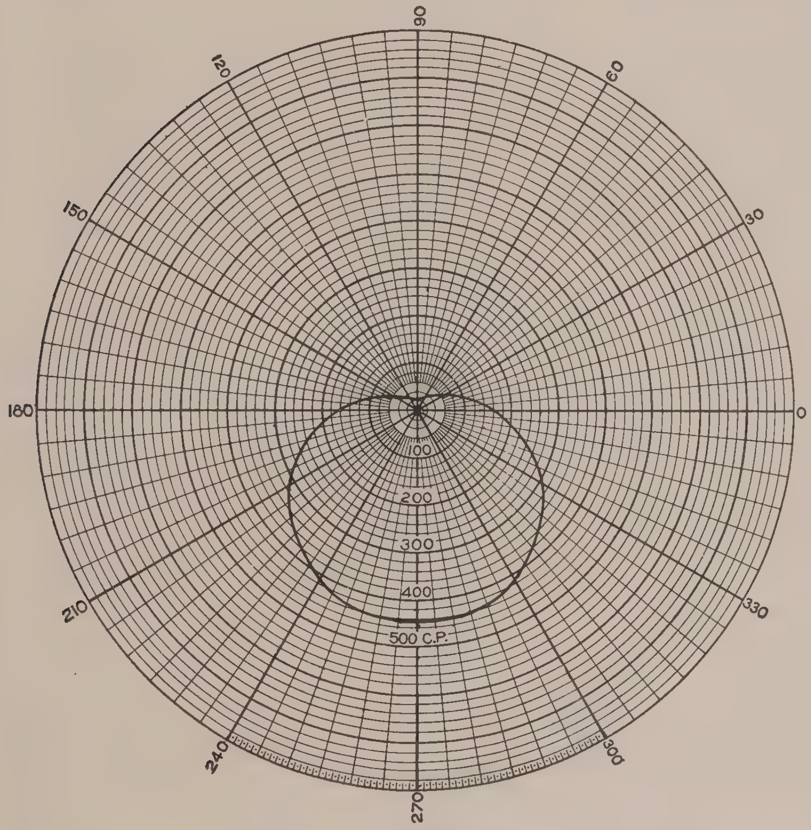


Fig. 25.

The Bremer Arc Lamp is one of the most favorable of several modifications of the arcs which have been proposed. This lamp uses very slender carbons having a core made of refractory oxides such as silica, lime, or magnesia. An efficiency of .1 to .4 watts per candle-power (mean spherical) has been claimed for this type of lamp, but it is still in the experimental stage.

The Mercury Vapor Lamp. Probably the Cooper Hewitt, or Mercury Vapor Lamp, is the only other special lamp deserving mention here. This lamp is being introduced to quite an extent where the quality of the light is not of so much importance. In this lamp, mercury vapor, rendered incandescent by the passage of an electric current, forms the source of light. One electrode is formed of mercury and the other may be of mercury or iron. In the more common type of lamp, these electrodes are mounted at the end of a long glass tube which has been very carefully exhausted. Fig. 26 shows such a lamp constructed for a 110-volt circuit. Dimensions of this lamp are as follows:

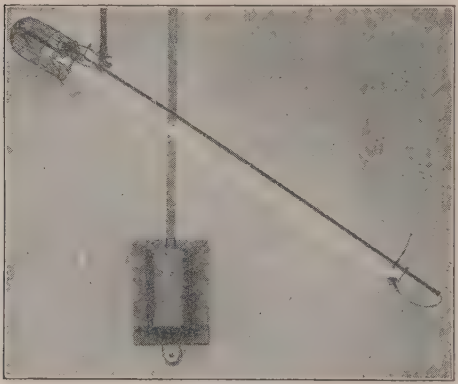


Fig. 26.

	For 100 Volts.	For 120 Volts.
Length of light-giving tube.......	43 inches.	49 inches.
Length over all.................	50 inches.	56 inches.
Diameter	1 inch.	

Current 3 to 3.5 amperes.
Candle Power at 120 volts, 750.
Life (average), 1,600 hours.

The mercury vapor, at the start, may be formed in two ways. First, the lamp may be tipped so that a stream of mercury makes contact between the two electrodes and mercury is vaporized when the stream breaks. Second, by means of a high inductance and a quick break switch; a very high voltage, sufficient to pass current from one electrode to the other, is induced and the conducting vapor formed. The lamp, as now manufactured, will operate only on direct current, but the alternating-current lamp is being developed.

Fig 27 is a diagram of a lamp connected for starting by the quick-break method, while Fig. 28 shows two 55-volt lamps connected in series on a 110-volt circuit, and arranged to be started by tipping. A steadying resistance and reactance are connected as shown in the diagram, the two being mounted on one base which may readily be attached to the wall as shown in Fig. 26.

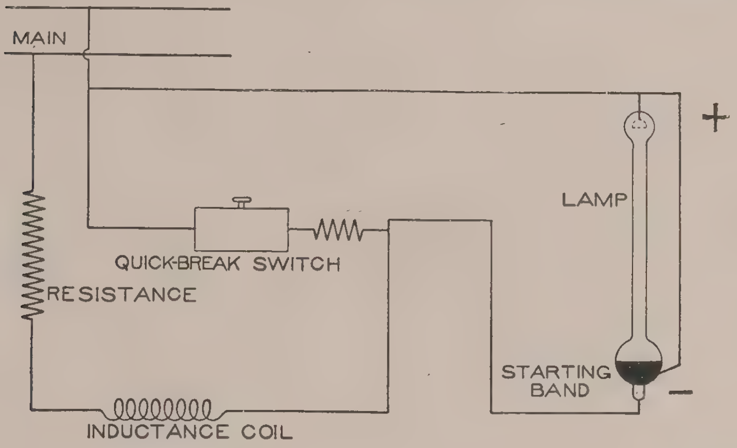


Fig. 27.

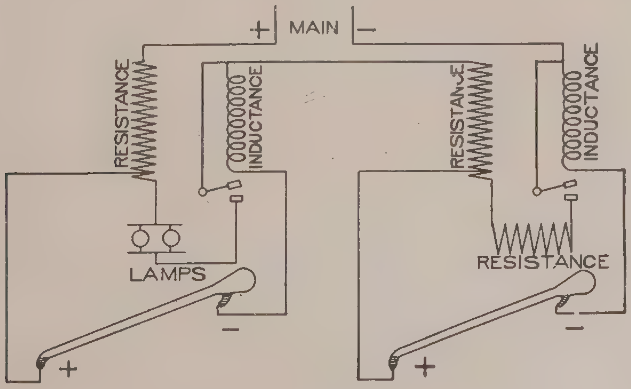


Fig. 28.

The mercury vapor lamp is not made in small sizes for ordinary voltages, and its light is very objectionable for the purpose of distinguishing color, as there is an entire absence of red rays.

This absence of the red light makes the illumination one that is very easy on the eyes but, on account of the color, its use is limited to the lighting of shops, offices, and drafting rooms, or in display windows where the goods shown are not changed in appearance by its color. It is also coming into use to a large extent in photographic work on account of the actinic properties of its light.

POWER DISTRIBUTION.

The question of power distribution for electric lamps and other appliances is taken up fully in the section on that subject, therefore it will be treated very briefly here. The systems may be divided into:

1. Series Distribution Systems.
2. Multiple-Series or Series-Multiple Systems.
3. Multiple or Parallel Systems.

They apply to both alternating and direct current.

The Series System is the most simple of the three; the lamps, as the name indicates, being connected in series as shown in Fig. 29. A constant load is necessary if a constant potential is to be used. If the load is variable, a constant-current generator, forms of which are described in "Types of Dynamo-Electric Machinery", or a special regulating device is necessary. Such devices are constant-current transformers and constant-current regulators as applied to alternating-current circuits.

The series system is used mostly for arc and incandescent lamps when applied to street illumination. Its advantages are simplicity and saving of copper. Its disadvantages are high voltage, fixed by the number of lamps in series; size of machines is limited since they cannot be insulated for voltage above about 6,000; a single open circuit shuts down the whole system.

Alternating-current series distribution systems are being used to a very large extent. By the aid of special transformers, or regulators, any number of circuits can be run from one machine or set of bus bars, and apparatus can be built for any voltage and of any size. It is not customary, however, to build transformers of this type having a capacity greater than 100, 6.6-ampere lamps.

The constant-current transformer most in use for lighting purposes is the one manufactured by the General Electric Company and commonly known as a "tub" transformer. Fig. 30 shows such a transformer when removed from the case, and Fig. 29 gives a diagram of the connection of a single-coil transformer in service.

Referring to Fig. 30, the fixed coils A form the primaries which are connected across the line; the movable coils B are the secondaries connected to the lamps. There is a repulsion of the coils B by the coils A when the current flows in both circuits and this force is balanced by means of the weights at W, so that the coils B take a position such that the normal current will flow in the secondary. On light loads, a low voltage is sufficient, hence the secondary coils are close together near the middle of the machine and there is a heavy magnetic leakage. When all of the lamps are on, the coils take the position shown when the leakage is a minimum and the voltage a maximum. When first starting up, the transformer is short-circuited and the secondary coils brought close together. The short circuit is then removed and the coils take a position corresponding to the load on the line.

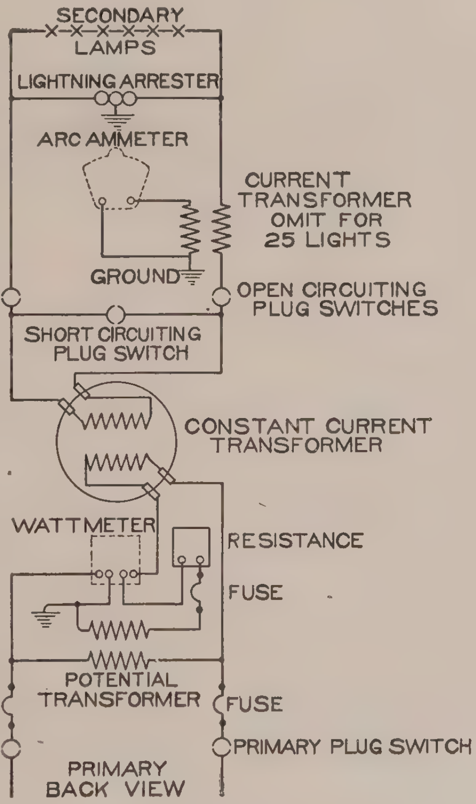


Fig. 29.

These transformers regulate from full load to $\frac{1}{3}$ rated load within $\frac{1}{10}$ ampere of normal current, and can be run on short circuit for several hours without overheating. The efficiency is given as 96% for 100-light transformers and 94.6% for 50-light transformers at full load. The power factor of the system is from

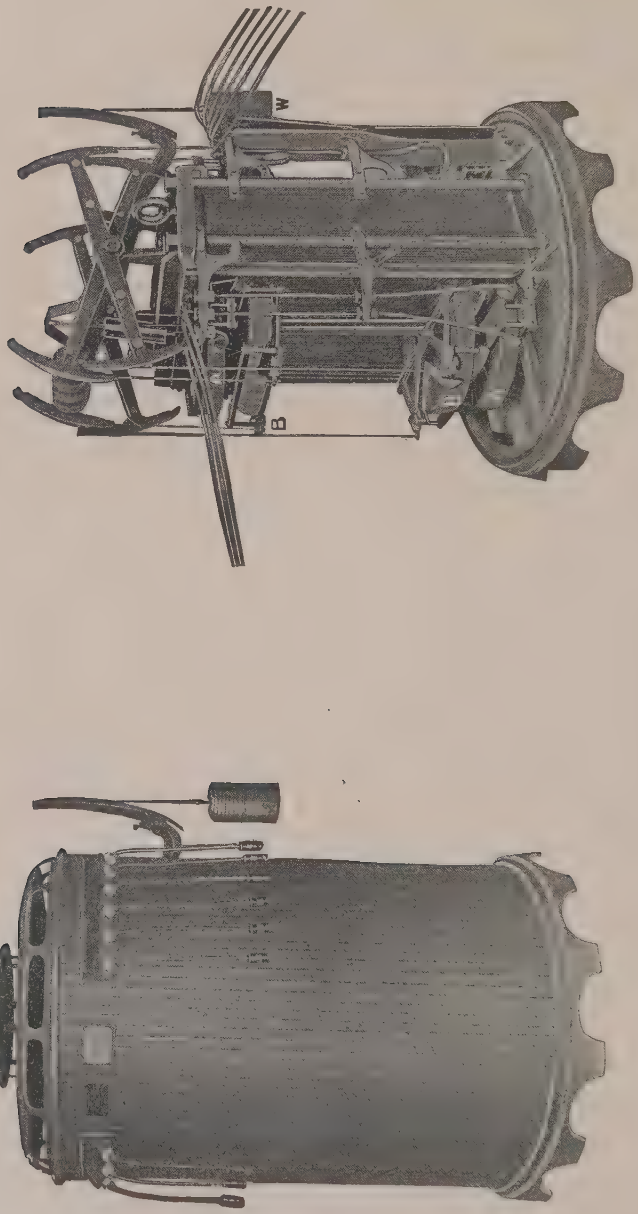


Fig. 30.

76 to 78% on full load, and, owing to the great amount of magnetic leakage at less than full load, the effect of leakage being the same as the effect of an inductance in the primary, the power factor is greatly reduced, falling to 62% at $\frac{3}{4}$ load, 44% at $\frac{1}{2}$ load, and 24% at $\frac{1}{4}$ load.

Standard sizes are for capacities of 25, 35, 50, 75, and 100, 6.6 ampere enclosed arcs. The low power factor of such a system on light loads shows that a transformer should be selected of such a capacity that it will be fully or nearly fully loaded at all times. The primary winding can be constructed for any voltage and the open circuit voltages of the secondaries are as follows:

25	light	transformer,	2300	volts.
35	"	"	3200	"
50	"	"	4600	"
75	"	"	6900	"
100	"	"	9200	"

The 50-, 75-, and 100-light transformers are arranged for multiple circuit operation, two circuits used in multiple, and the voltages at full load reach 4,100 for each circuit on the 100-light machine.

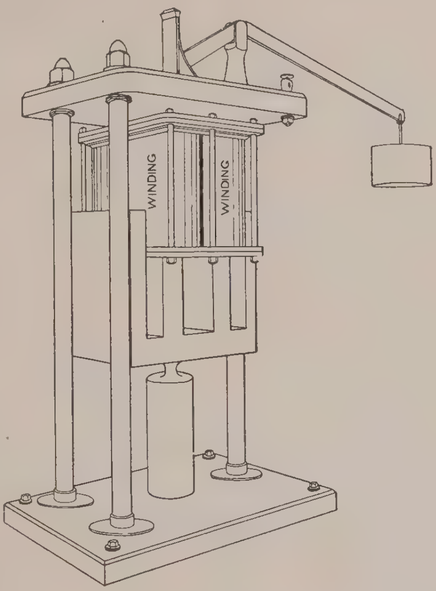


Fig. 31.

The second system, used for series distribution on alternating-current circuits, consists of a constant-potential transformer, stepping down the line voltage to that required for the total number of lamps on the system, allowing 83 volts for each lamp, and in series with the lamps is a reactive coil, the reactance of which is automatically regulated, as the load is increased or decreased, in order to keep the current in the line constant. Fig. 31 shows such a regulator as manufactured by the General Incandescent Arc Light Company, and Fig. 32 shows this regulator connected in circuit. The inductance is varied by the movement of the coil to include more or less iron in the magnetic circuit. Since the inductance in series with the lamps is high on light loads, the power factor is greatly reduced as in the constant-current transformer; and the circuits should, preferably, be run fully loaded. 60 to 65 lamps on a circuit is the maximum limit.

While used primarily for arc-light circuits, the same systems, designed for lower currents, are very readily applied to series incandescent systems.

Multiple-series and series-multiple systems combine several lamps in series and these groups in multiple, or several lamps in multiple and these groups in series, respectively. They have but a limited application.

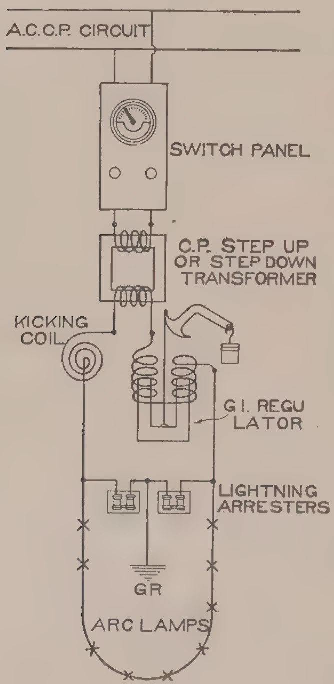


Fig. 32.

Multiple or Parallel Systems of Distribution. By far the largest number of lamps in service are connected to parallel systems of distribution. In this system, the units are connected across the lines leading to the bus bars at the station, or to the secondaries of constant-potential transformers. Fig. 33 shows a diagram of ten lamps connected in parallel. The current delivered by the machine depends directly on the number of lamps connected in service, the voltage of the system being kept constant.

Inasmuch as the flow of current in a conductor is always accompanied by a fall of potential equal to the product of the current flowing, into the resistance of the conductor, the lamps at the end of the system shown will not have as high a voltage impressed upon them as those nearer the machine. This drop in potential is the most serious obstacle that we have to overcome in multiple systems, and various schemes have been adopted to aid in this regulation. The systems may be classified as:

First, Cylindrical Conductors, parallel feeding.
Second, Conical “ “ “
Third, Cylindrical “ anti-parallel feeding.
Fourth, Conical “ “ “

In the cylindrical conductor, parallel-feeding system, the conductors, A, B, C, D, Fig. 33, are of the same size throughout and are fed at the same end by the generator. The voltage is a minimum at the lamps E and a maximum at the lamps F; the value of the voltage at any lamp being readily calculated.

By a conical or tapering conductor is meant a conductor whose diameter is so proportioned throughout its length that the current, divided by the cross-section or the current density, is a constant quantity. Such a conductor is approximated in practice by using smaller sizes of wire as the current in the lines becomes less.

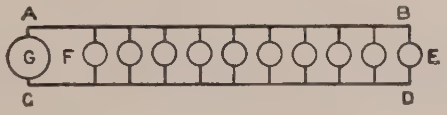


Fig. 33.

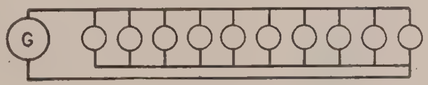


Fig. 34.

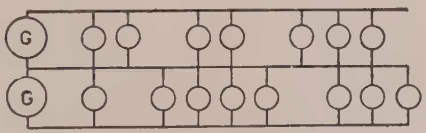


Fig. 35.

In an anti-parallel system, the current is fed to the lamps from opposite ends of the system as shown in Fig. 34.

Multiple-Wire Systems. In order to take advantage of a higher voltage for distribution of power to the lighting circuits, three- and five-wire systems have been introduced, the three-wire system being used to a very large extent. In this system, three conductors are used, the voltage from each outside conductor and the middle neutral conductor being the same as for a simple parallel system. Fig. 35 gives a diagram of this. By this system the amount of copper required for a given number of lamps is from five-sixteenths to three-eighths of the amount required for a two-wire distribution, depending on the size of the neutral conductor. The saving of copper together with the disadvantages of the system is more fully treated in the paper on Power Transmission.

ILLUMINATION.

Illumination may be defined as the quality and quantity of light which aids in the discrimination of outline and the perception of color. Not only the quantity, but the quality of the light, as well as the arrangement of the units, must be considered in a complete study of the subject of illumination.

The Unit of Illumination is the *candle-foot* and its value is the amount of light falling on a surface at a distance of one foot from a source of light one candle-power in value. The law of inverse squares, namely, that the illumination from a given source varies inversely as the square of the distance from the source, shows that the illumination at a distance of two feet from a single candle-power unit is .25 candle-foot. For further consideration of the law of inverse squares, see " Photometry ".

Illumination may be classified as *useful* illumination, when used for the ordinary purposes of furnishing light for carrying on work, taking the place of daylight, and *scenic* illumination. The latter applies to all forms of decorative lighting such as stage lighting, etc. The two divisions are not, as a rule, distinct, but the one is combined with the other.

Intrinsic Brightness. By intrinsic brightness is meant the amount of light emitted per unit surface of the light source. Table 3 gives the intrinsic brightness of several light sources.

TABLE 3.

Intrinsic Brilliancies in Candle-Power per Square Inch.

Source	Brilliancy	Notes.
Sun in zenith	600,000	Rough equivalent values, taking account of absorption.
Sun at 30 degrees elev.	500,000	
Sun on horizon	2,000	
Arc light	10,000 to 100,000	Maximum about 200,000 in crater.
Calcium light	5,000	
Nernst "glower"	1,000	Unshaded.
Incandescent lamp	200–300	Depending on efficiency.
Enclosed arc	75–100	Opalescent inner globe.
Acetylene flame	75–100	
Welsbach light	20 to 25	
Kerosene light	4 to 8	Variable.
Candle	3 to 4	
Gas flame	3 to 8	Variable.
Incandescent (frosted)	2 to 5	
Opal shaded lamps, etc.	0.5 to 2	

HOLOPHANE EXHIBIT.

World's Fair, St. Louis.

Regular Reflection. Regular reflection is the term applied to reflection of light when the reflected rays are parallel. It is of such a nature that the image of the light source is seen in the reflection. The reflection from a plane mirror is an example of this. It is useful in lighting in that the direction of light may be changed without complicating calculations aside from deductions necessary to compensate for the small amount of light absorbed.

Irregular Reflection, or diffusion, consists of reflection in which the reflected rays of light are not parallel but take various directions, thus destroying the image of the light source. Rough, unpolished surfaces give such reflection. Smooth, unpolished surfaces generally give a combination of the two kinds of reflection. Diffused reflection is very important in the study of illumination inasmuch as diffused light plays an important part in the lighting of interiors. This form of reflection is seen in many photometer screens. Light is also diffused when passing through semi-transparent shades or screens.

In considering reflected light, we find that, if the surface on which the light falls is colored, the reflected light may be changed in its nature by the absorption of some of the colors. Since, as has been said, in interior lighting the reflected light forms a large part of the source of illumination, this illumination will depend upon the nature and color of the reflecting surfaces.

Whenever light is reflected from a surface, either by direct or diffused reflection, a certain amount of light is absorbed by the surface. Table 4 gives the amount of white light reflected from different materials.

TABLE 4.

Material.	
White blotting paper	.82
White cartridge paper	.80
Chrome yellow paper	.62
Orange paper	.50
Yellow wall paper	.40
Light pink paper	.36
Yellow cardboard	.30
Light blue cardboard	.25
Emerald green paper	.18
Dark brown paper	.13
Vermilion paper	.12
Blue-green paper	.12
Black paper	.05
Black cloth	.012
Black velvet	.004

From this table it is seen that the light-colored papers reflect the light well, but of the darker colors only yellow has a comparatively high coefficient of reflection. Black velvet has the lowest value, but this only holds when the material is free from dust. Rooms with dark walls require a greater amount of illuminating power, as will be seen later.

Useful illumination may be considered under the following heads:

1. Residence Lighting.
2. Lighting of Public Halls, Offices, Drafting Rooms, Shops, etc.
3. Street Lighting.

RESIDENCE LIGHTING.

Type of Lamps. The lamps used for this class of lighting are limited to the less powerful units, namely, incandescent or Nernst lamps varying in candle-power from 8 to 32 per unit. These should always be shaded so as to keep the intrinsic brightness low. The intrinsic brilliancy should seldom exceed 2 to 3 candle-power per square inch, and its reduction is usually accomplished by appropriate shading. Arc lights are so powerful as to be uneconomical for small rooms, while the color of the mercury-vapor light is an additional objection to its use.

Plan of Illumination. Lamps may be selected and so located as to give a brilliant and fairly uniform illumination in a room; but this is an uneconomical scheme, and the one more commonly employed is to furnish a uniform, though comparatively weak, ground illumination, and to reinforce this at points where it is necessary or desirable. The latter plan is satisfactory in almost all cases and the more economical of the two.

While the use of units of different power is to be recommended, where desirable, lights differing in color should not be used for lighting the same room. As an exaggerated case, the use of arc with incandescent lamps might be mentioned. The arcs being so much whiter than the incandescent lamps, the latter appear distinctly yellow when the two are viewed at the same time.

Calculation of Illumination. In determining the value of illumination, not only the candle-power of the units, but the amount of reflected light must be considered for the given location of the lamps. Following is a formula based on the coefficient of reflection of the walls of the room, which serves for preliminary calculations:

$$I = \frac{c.p. \; \frac{1}{1-k}}{d^2}$$

I = Illumination in candle-feet.
c.p. = Candle-power of the unit.
k = Coefficient of reflection of the walls.
d = distance from the unit in feet.

Where several units of the same candle-power are used this formula becomes

$$I = c.p. \left(\frac{1}{d^2} + \frac{1}{d_1^2} + \frac{1}{d_2^2} + \text{---------}\right) \frac{1}{1-k}$$

or,

$$c.p. = \frac{I}{\left(\frac{1}{d^2} + \frac{1}{d_1^2} + \frac{1}{d_2^2} + \text{---------}\right) \frac{1}{1-k}}$$

where d, d_1, d_2, etc., equal the distances from the point considered to the various light sources. If the lamps are of different candle-power, the illumination may be determined by combining the illumination from each source as calculated separately. An example of calculation is given under "Arrangement of Lamps".

It is readily seen that the effect of reflected light from the ceilings is of more importance than that from the floor of a room. The value of *k*, in the above formula, will vary from 60% to 10%, but for rooms with a fairly light finish 50% may be taken as a good average value.

The amount of illumination will depend on the use to be made of the room. One candle-foot gives sufficient illumination for easy reading, when measured normal to the page, and probably an illumination of .5 candle-foot on a plane 3 feet from the floor forms a sufficient ground illumination. The illumination from sunlight reflected from white clouds is from 20 candle-feet up, while that due to moonlight is in the neighborhood of .03 candle-foot. It is not possible to produce artificially a light equivalent to daylight on account of the great amount of energy that would be required and the difficulty of obtaining proper diffusion.

Arrangement of Lamps. An arrangement of lamps giving a uniform illumination cannot be well applied to residences on account of the number of units required, and the inartistic effect. We are limited to chandeliers, side lights, or ceiling lights, in the majority of cases, with table or reading lamps for special illumination.

When ceiling lamps are used and the ceilings are high, some form of reflector or reflector lamp is to be recommended. In any case where the coefficient of reflection of the ceilings is less than 40%, it is more economical to use reflectors. When lamps are mounted on chandeliers, the illumination is far from uniform, being a maximum in the neighborhood of the chandelier and a minimum at the corners of the room. By combining chandeliers with side lights it is generally possible to get a satisfactory arrangement of lighting for small or medium-sized rooms.

As a check on the candle-power in lamps required, we have the following:

For brilliant illumination allow one candle power per two square feet of floor space. In some particular cases, such as ball rooms, this may be increased to one candle-power per square foot.

For general illumination allow one candle-power for four square feet of floor space, and strengthen this illumination with the aid of special lamps as required. The location of lamps and the height of ceilings will modify these figures to some extent.

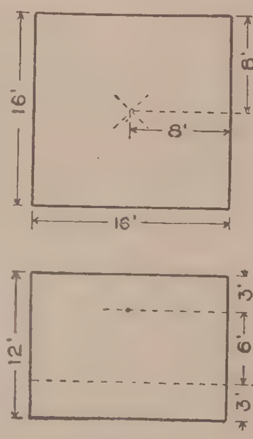


Fig. 36.

As an example of the calculation of the illumination of a room with different arrangements of the units of light, assume a room 16 feet square, 12 feet high, and with walls having a coefficient of reflection of 50%. Consider first the illumination on a plane 3 feet above the floor when lighted by a single group of lights mounted at the center of the room 3 feet below the ceiling. If a minimum value of .5 candle-foot is required at the corner of the room we have the equation

$$.5 = c.p.\frac{1}{12.8^2} \times \frac{1}{1 - .5}$$

Since $d = \sqrt{8^2 + 8^2 + 6^2} = 12.8$ (see Fig. 36)

Solving the above for the value of *c.p.*, we have

$$c.p. = \frac{.5}{\frac{1}{164} \times \frac{1}{.5}} = .5 \times 82 = 41$$

Three 16-candle-power lamps would serve this purpose very well.

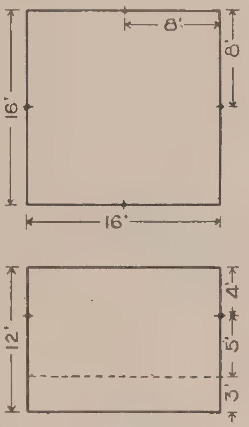


Fig. 37.

Determining the illumination directly under the lamp, we have:

$$I = 48 \times \frac{1}{6^2} \times \frac{1}{1 - .5} = \frac{48}{36} \times 2 =$$

2.7 candle-feet, or five times the value of the illumination at the corners of the room.

Next consider four 8-candle-power lamps located on the side walls 8 feet above the floor as shown in Fig. 37. Calculating the illumination at the center of the room on a plane three feet above the floor, we have:

$$I = 8\left(\frac{1}{89} + \frac{1}{89} + \frac{1}{89} + \frac{1}{89}\right) \frac{1}{1 - .5}$$

$$d^2 = 8^2 + 5^2 = 64 + 25 = 89$$

$$I = 8 \times \frac{4}{89} \times 2 = .72 \text{ candle-foot.}$$

The illumination at the corner of the room would be:

$$I = 8\left(\frac{1}{89} + \frac{1}{89} + \frac{1}{345} + \frac{1}{345}\right) \frac{1}{1 - .5}$$

$$= 8\left(\frac{2}{89} + \frac{2}{345}\right) \times 2 = .45 \text{ candle-foot.}$$

In a similar manner the illumination may be calculated for any point in the room, or a series of points may be taken and curves plotted showing the distribution of the light, as well as the areas having the same illumination. Where refined calculations are desired, the distribution curve of the lamp must be used for deter-

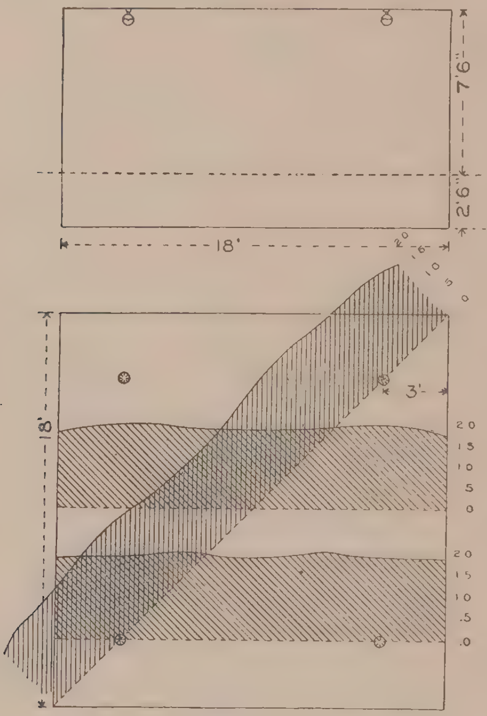


Fig. 38.

mining the candle-power in different directions. Fig. 38 shows illumination curves for the Meridian lamp manufactured by the General Electric Company. This is a form of reflector lamp made in two sizes, 25 or 50 candle-power. Fig. 39 gives the distribution curves for the 50-candle-power unit. Similar incandescent lamps are now being manufactured by other companies.

Table 5 gives desirable data in connection with the use of the Meridian lamp.

By means of the Weber, or some other form of portable photometer, curves as plotted from calculations may be readily checked after the lamps are installed. When lamps are to be permanently located, the question of illumination becomes an

TABLE 5.

Illuminating Data for Meridian Lamps.

Class Service.	Light Intensity in Candle-feet.	No. 1 Lamp (60 Watts)		No. 2 Lamp (120 Watts)		Watts per Sq. Ft. of Area Lighted With Either Lamp.
		Height of Lamp and Diameter of Uniformly Lighted Area.	Distance Between Lamps When Two or More are Used.	Height of Lamp and Diameter of Uniformly Lighted Area.	Distance Between Lamps When Two or More are Used.	
Desk or Reading Table.	3	2.9 feet.	4.9 feet.	4 feet.	7 feet.	2.50
	2	3.5 "	6 "	5 "	8.5 "	1.66
	1½	4 "	7 "	5.75 "	9.8 "	1.25
General Lighting.	1	5 "	8.5 "	7 "	12 "	0.83
	¾	5.75 "	9.8 "	8.2 "	13.9 "	0.62
	½	7 "	12 "	10 "	11 "	0.41

important one, and it is customary to determine, by calculation, the illumination curves and the isophotals, Fig. 38, as the lines showing equal illumination are called, for each room before installing the lamps. This applies to the lighting of large interiors more particularly than to residence lighting.

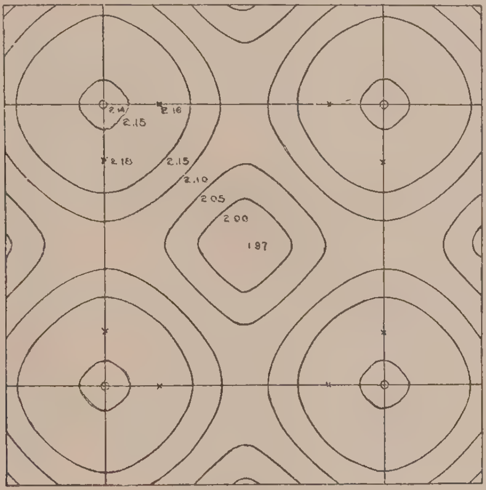


Fig. 38.

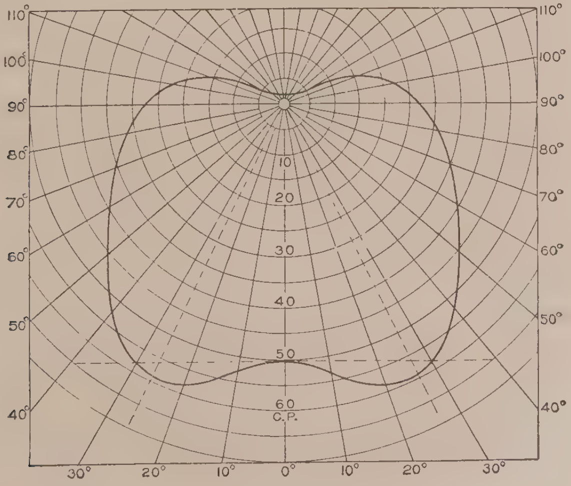


Fig. 39.

Dr. Louis Bell gives the following in connection with residence lighting:

TABLE 6.

Room.	8 c.p.	16 c.p.	32 c.p.	Sq. ft. per c.p.	Remarks.
Hall, 15′ × 20′	8			4.7	
Library, 20′ × 20′	12		1	3.1	8-c.p. reflector lamps.
Reception room, 15′ × 15′	4			7.0	
Music room, 20′ × 25′	12		2	3.0	
Dining room, 15′ × 20′	14			2.7	8 reflect'r lamps
Billiard room, 15′ × 20′			4	2.3	32-c.p. with reflectors.
Porch			1		
Bedrooms (6), 15′ × 15′		14		7.0	
Dressing rooms (2), 10′ × 15′		4		4.7	
Servants' rooms (3), 10′ × 15′		3		9.4	
Bathrooms (3), 8′ × 10′		3		5.0	
Kitchen, 15′ × 15′ Pantry, 10′ × 15′		3			
Halls Cellar	10	3			
Closets (4)	4				Reflector lamps
Total	64	30	8		

LIGHTING OF PUBLIC HALLS, OFFICES, ETC.

Lighting of public halls and other large interiors differs from the illumination of residences in that there is usually less reflected light, and, again, the distance of the light sources from the plane of illumination is generally greater if an artistic arrangement of the lights is to be brought about. This in turn reduces the direct illumination. The primary object is, however, as in residence lighting, to produce a fairly uniform ground illumination and to superimpose a stronger illumination where necessary. An illlumination of .5 candle-feet for the ground illumination may be taken as a minimum.

In the lighting of large rooms it is permissible to use larger light units, such as arc lamps and high candle-power Nernst or incandescent units, while for factory lighting and drafting rooms, where the color of the light is not so essential, the Cooper Hewitt lamp is being introduced. High candle-power reflector lamps, such as the Meridian lamp, are being used to a large extent for offices and drafting rooms.

The choice of the type of lamp depends on the nature of the work. Where the light must be steady, incandescent or Nernst lamps are to be preferred to the arc or vapor lamps, though the latter are often the more efficient. When arcs are used, they must be carefully shaded so as to diffuse the light, doing away with the strong shadows due to portions of the lamp mechanism, and to reduce the intrinsic brightness. Such shading will be taken up under the heading "Shades and Reflectors". Arcs are preferable to incandescent lamps when colored objects are to be illuminated, as in stores and display windows.

In locating lamps for this class of lighting, much depends on the nature of the building and on the degree of economy to be observed. For preliminary determination of the location of groups, or the illumination when certain arrangement of the units is assumed, the principles outlined under "Residence Lighting" may be applied. It has been found that actual measurements show results approximating closely such calculated values.

When arcs are used they should be placed fairly high, twenty to twenty-five feet when used for general illumination and the ceilings are high. They should be supplied with reflectors so as to utilize the light ordinarily thrown upwards. When used for drafting-room work, they should be suspended from twelve to fifteen feet above the floor, and special care must be taken to diffuse the light.

Incandescent lamps may be arranged in groups, either as side lights or mounted on chandeliers, or they may be arranged as a frieze running around the room a few feet below the ceiling. The last named arrangement of lights is one that may be made artistic, but it is uneconomical and when used should serve for the ground illumination only. Reflector lights may be used for this style of work and the lights may be entirely concealed from view, the reflecting property of the walls being utilized for distributing the light where needed.

Ceiling lights should preferably be supplied with reflectors, especially when the ceilings are high.

Measurements taken in well-lighted rooms having a floor space of from 1,000 to 5,000 square feet show an average of 3 to 3.5 square feet per candle-power. About 2.5 square feet per candle-power should be allowed when brilliant lighting is required or the ceilings are very high, while 3.75 square feet per candle power

TABLE 7.

Lighting Data for Arc Lamps.

Place Lighted.	Clothing Store	Weave Room.	Erecting Room.	Machine Shop.	Drafting Room.	Drafting Room.	Ship Shed.	Cataloging Dept.	Jewelry Store.
No. of sq. ft. place lighted...	4000	14400	281600	42250	6275	5690	69000	4136	4000
No. lamps used..............	12	50	200	42	27	24	50	17	6
Circuit..........................	A. C. Mult	D. C. Mult.	D. C. Mult.	D. C. Mult.	A. C. Series.	D. C. Mult.	*D. C. Mult.	D. C. Mult.	D. C. Mult.
Cycles....	60	......	......	......	60	......	......	......	......
Volts line....................	104	110	120	120	......	120	220	110	110
Amperes........................	6	3¼	6.2	6.2	7.5	4	6	4½	5
Volts at arc..................	72	75	80	80	72	80	80	80	80
Power factor of lamp........	.69	......	......	......	.86	......	......	......	......
Watts per lamp..............	430	357	744	744	490	480	660	495	550
Watts per sq. ft. (term.).....	1.29	1.24	.53	.74	2.11	2.02	.478	2.03	.825
Kw. at term. (whole installation)	5.16	17.8	148.8	31.25	13.22	11.52	33	8.42	3.3
Kw. at arc (whole installation)	4.62	12.28	99.2	20.8	12.42	7.68	24	6.12	2.4
Sq. ft. lighted per lamp......	333	288	1408	1006	232	237	1380	243	667
Sq. ft. lighted per amp.......	55.6	88.6	227	162	31	59.2	230	54.1	133.5
Enclosing globe.............	Opal		Opal.	Opal.	Opal.	Opal.		Opal.	Opal.
Height and style of ceiling..	12′ white steel.	Saw Toothed.	Trussed.	Trussed.	12′ White.	Trussed.	160′ Trussed.	13′ 9″ Maroon.	16′ 10′ White.
Reflector system used.......	Concentric Diffuser.	Adjust. Diffuser	9″ Mirror.	9″ Mirror.	Concentric Diffuser.	16 Adj. Dif. 8 Con. Dif.	12″ Mirror.	Concentric Diffuser.	Concentric Diffuser.
Height of arc from floor.....	9′ 6″	12′ to 15′	46′	47′	9′	15′	150′	10′ 7″	13′ 2″
Distance between lamps	14′ to 18′	24′	32′ to 38′	30′ 9″	15′	12′ to 25′	17′ to 20′	14′ to 18′	16′ to 25′

will give good illumination when lights are well distributed and there is considerable reflected light.

In factory and drafting room lighting, the lamps must be arranged to give a strong light where most needed, and located to prevent such shadows as would interfere with the work.

Following are tables showing the number and distribution of arc and mercury-vapor lamps for lighting large rooms. Table 7 refers to arc lights as actually installed.

TABLE 8.

Lighting Data for Cooper-Hewitt Lamps.

Drafting Room.	2,140 sq. ft.	8 V-5 lamps.
	265 sq. ft. per lamp.	8 × 3.3 amperes = 26.5 amp.
	voltage 110.	80 sq. ft. per amp.
Office.	1,100 sq. ft.	3 H–4 lamps.
	366 sq. ft. per lamp.	3x3.3 amp. = 10 amp.
	voltage 110.	110 sq. ft. per amp.
Factory.	12,000 sq. ft.	30 V–4 lamps.
	400 sq. ft. per lamp.	30x1.7 amp. = 51 amp.
	voltage 110.	

STREET LIGHTING.

In studying the lighting of streets and parks, we find that, except in special cases, such as narrow streets and high buildings, there is no reflected light which aids the illumination aside from that due to special shades or reflectors on the lamp itself. Such reflectors are necessary if the light ordinarily thrown above the horizontal plane is to be utilized.

In calculating the illumination due to any type of lamp at a given point it is necessary to know the distribution curve of the lamp used and the distance to the point illuminated. The approximate illumination is given by the formula,

$$I = \frac{c.p.}{h^2 + d^2}$$

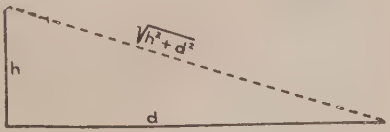


Fig. 40.

when I = illumination in candle-feet.

$c.p.$ = candle-power of the unit, determined from the distribution curve of the lamp.

h = distance the lamp is mounted above the ground, in feet, and d = distance from the base of the pole supporting the lamp to the point where the illumination is being considered. See Fig. 40.

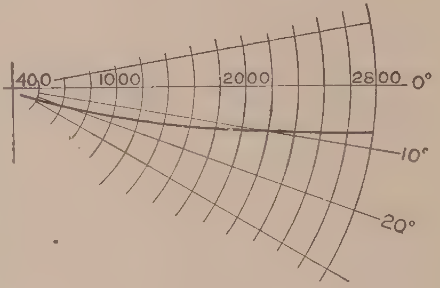


Fig. 41.

While this will give the illumination in candle-feet, the nature of the lighting cannot be decided from this alone, but the total amount of light must also be considered. Thus, a street lighted with powerful units and giving a minimum illumination of .05 candle-foot would be considered better illuminated than one having smaller units so distributed as to give the same minimum value.

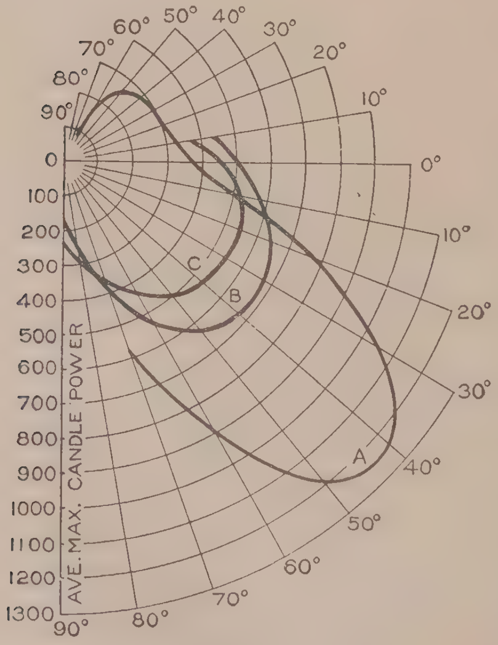


Fig. 42.

Since a uniform distribution of light is desirable, for economic reasons, the ideal distribution curve of a lamp for street lighting would be a curve which shows a low value of candle-power thrown directly downward, but with the candle-power increasing as we approach the horizontal. Such an ideal distribution curve is shown in Fig. 41.

Actual distribution curves taken from commercial arc lamps are given in Fig. 42, in which

Curve A shows distribution curve for a 9.6-ampere, open, direct-current arc.

Curve B shows distribution curve for a 6.6 ampere, D.C. enclosed arc.

Curve C shows distribution curve for a 7.5-ampere, A.C. enclosed arc.
Globes used with B and C are opal, inner globes, clear, outer globes.
Globes used with A are clear outer globes.
A street reflector was used with the enclosed arcs.

A series of curves known as illumination curves may be readily calculated showing the illumination in candle-feet at given distance from the foot of the pole supporting the lamp. Illumination curves corresponding to the distribution curves in Fig. 42 are given in Fig. 43 where A′, B′, and C′ correspond to A, B, and

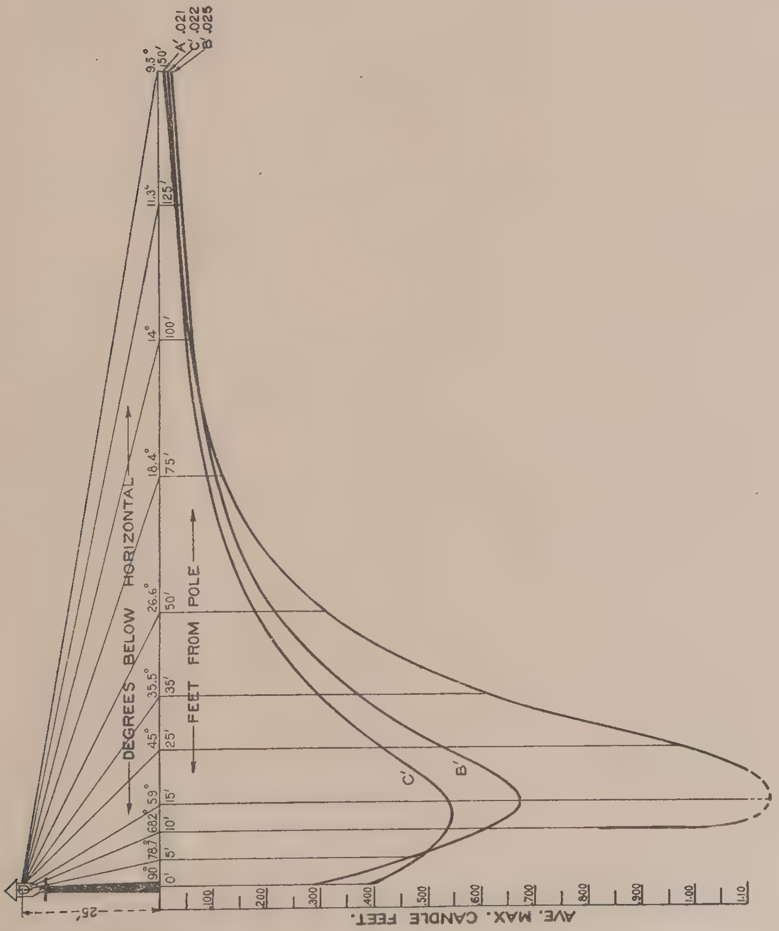


Fig. 43.

C in Fig. 42. These curves correspond to actual readings taken with commercial lamps. Similar curves for incandescent lamps are shown in Fig. 44. A value of .03 candle-foot is about the minimum for good street lighting. Open arcs should be placed at least 25 feet above the ground; 30 to 40 feet is better, especially if the space to be illuminated is quite open. With enclosed arcs it is often advantageous to place them as low as 18 to 20 feet from the ground. Table 9 gives the distance between lights for different types of arcs for good illumination.

TABLE 9.

Kind of Light.	Distance between Lights.	Lights Per Mile.
6.6-ampere enclosed D.C. arc	340 Feet.	15
9.6-ampere open D.C. arc	315 "	17
6.6-ampere enclosed A.C. arc	275 "	19
6.6-ampere open D.C. arc	260 "	20

In considering the type of arc light to be used we must turn to the illumination curves as shown in Fig. 43. These curves show that the illumination from a direct-current open arc in its present form is superior to that from a direct-current enclosed arc, taking the same amount of power, in the vicinity of the pole, but at a distance of 100 feet, the illumination from the enclosed arc is better. This illumination is still more effective on account of the absence of such strong light as is given by the open arc near the pole. The pupil of the eye adjusts itself to correspond to the brightest light in the field of vision, and we are unable to see as well in the dimly-lighted section as when the maximum intensity is less. The characteristics of the open, direct-current arc lamps are as follows:

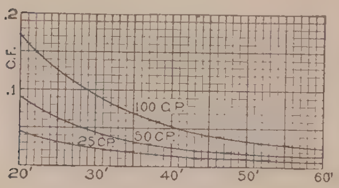


Fig. 44.

The mean spherical candle-power and energy required at the arc are variable.

Fluctuations of light are marked, due to wandering of the arc, flickering due to the wind and lack of uniformity of the carbons.

Dense shadows are cast by the side rods and the lower carbon, while the light is objectionably strong in the vicinity of the pole.

With the enclosed arc the mean spherical candle-power and the watts consumed at the arc are fairly constant.

No shadows are cast by the lamps, and the illumination is not subject to such wide variations. The enclosed arc is much superior to the open arc using the same amount of energy. This applies to the open arc as it is now used. With proper reflection and diffusion of the light such as might be accomplished by extensive or special shading, we ought to be able to get as good distribution from the open arc with a greater total amount of illumination.

In comparing the direct-current with the alternating-current enclosed arc, we see that the direct-current arc gives slightly more light than the alternating lamp, but this may be more than counterbalanced by the better distribution of light from the alternating-current lamp. The selection of A.C. or D.C. enclosed lamps will usually depend on other conditions, such as method of distribution of power, efficiency of plant, etc.

Series incandescent lamps are used considerably for lighting the streets in residence sections of cities or where shade trees make it impracticable to use arcs. These vary in candle-power from 16 to 50 or even higher, and are usually constructed so as to take from two to four amperes. The best arrangement of these is to mount them on brackets a few feet from the curb, with alternate lamps on opposite sides of the street. The distance between the lamps depends on their power. 50 candle-power lamps spaced 100 feet between lamps, give a minimum illumination of .02 candle-foot. 25 candle-power lamps spaced 75 feet between lamps will serve where economy is necessary.

SHADES AND REFLECTORS.

Lamps, as ordinarily constructed, do not always give a suitable distribution of light, while the intrinsic brightness is often too high for interior lighting. Shades are intended to modify the intensity of the light, while reflectors are used for the purpose of changing its direction. Frequently the two are combined in various ways. Shades are also used for decorative purposes, but, if possible, these should be of such a nature as to aid illumination rather than to reduce its efficiency.

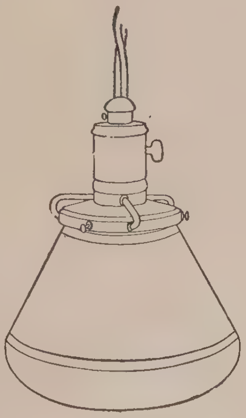


Fig. 45.

A considerable amount of light is absorbed by the material used for the construction of shades. Table 10 shows the approximate amount absorbed by some materials.

Of the great number of styles of shades and reflectors in use, only a few of the more important will be considered here.

TABLE 10.

	Per Cent.
Clear glass	10
Alabaster glass	15
Opaline glass	20–40
Ground glass	25–30
Opal glass	25–60
Milky glass	30–60
Ground glass	24.4
Prismatic glass	20.7
Opal glass	32.2
Opaline glass	23.0

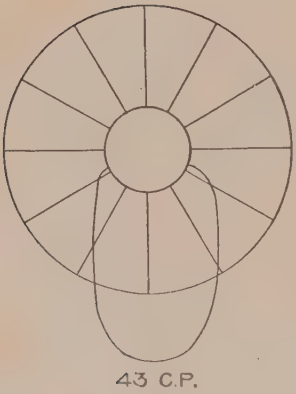


Fig. 46.

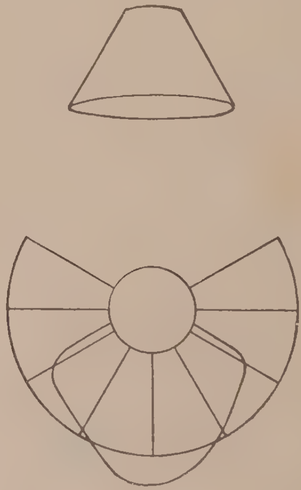
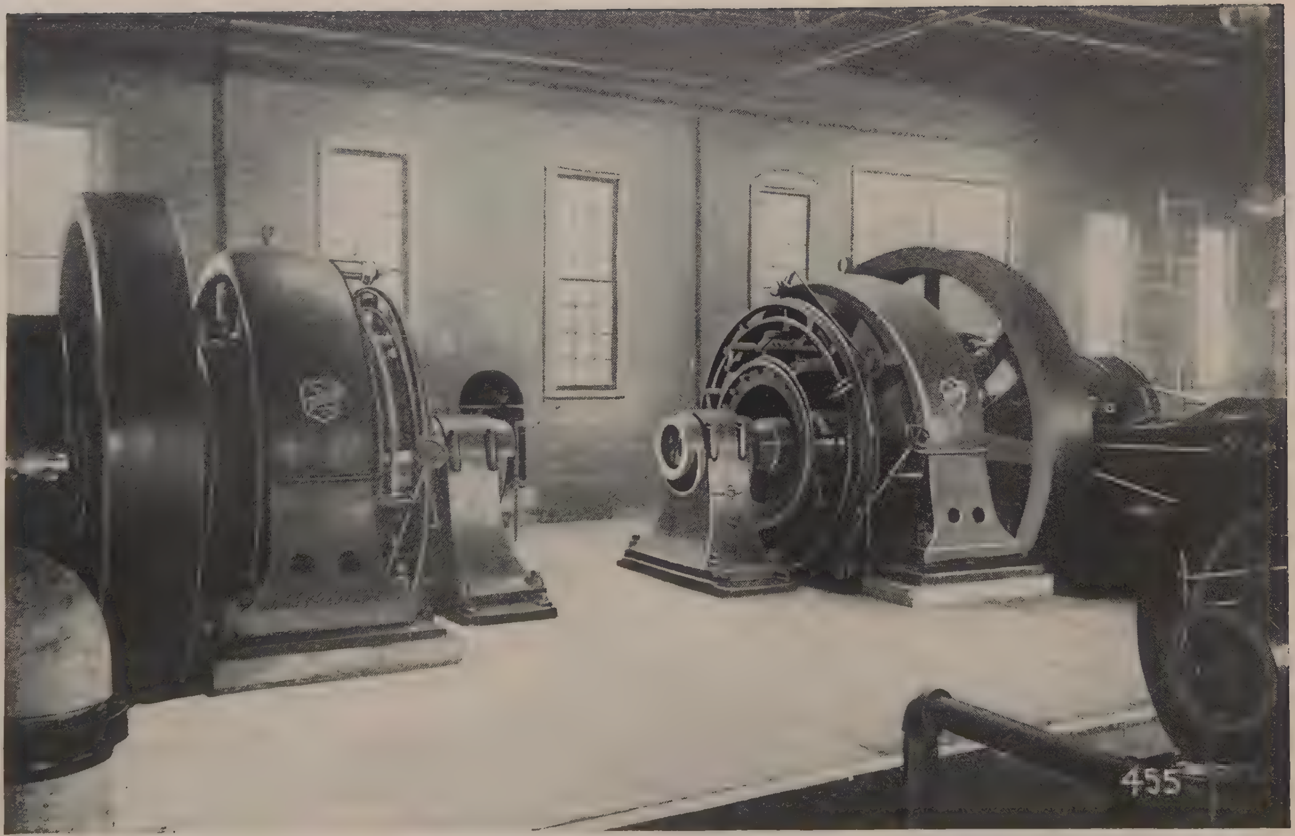


Fig. 47.

One of the simplest methods of shading incandescent lamps is by the use of "frosted" globes. These serve to reduce the intrinsic brightness of the lamp, and should be freely used for residence lighting when separate shades are not installed. Frosted globes are also used in connection with reflectors for the purpose of diffusing the reflected light. The McCreary shade as shown in



ENGINE-TYPE GENERATORS

in Republic Rubber Works, Youngstown, Ohio.
Bullock Electric Manufacturing Co.

Fig. 45 is an example of such a combined shade and reflector. Fig. 46 shows the distribution curve taken from an incandescent lamp using a McCreary shade. Fig. 47 shows the distribution of light from a conical shade. Fig. 39 shows the distribution of light brought about by means of a spiral filament and a reflector as used in the Meridian lamp.

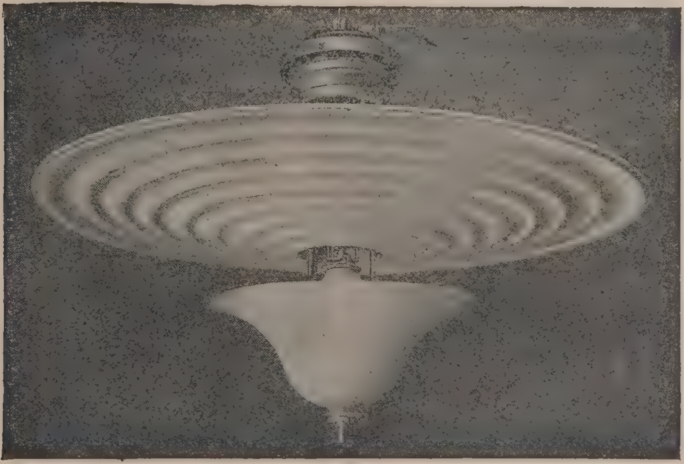
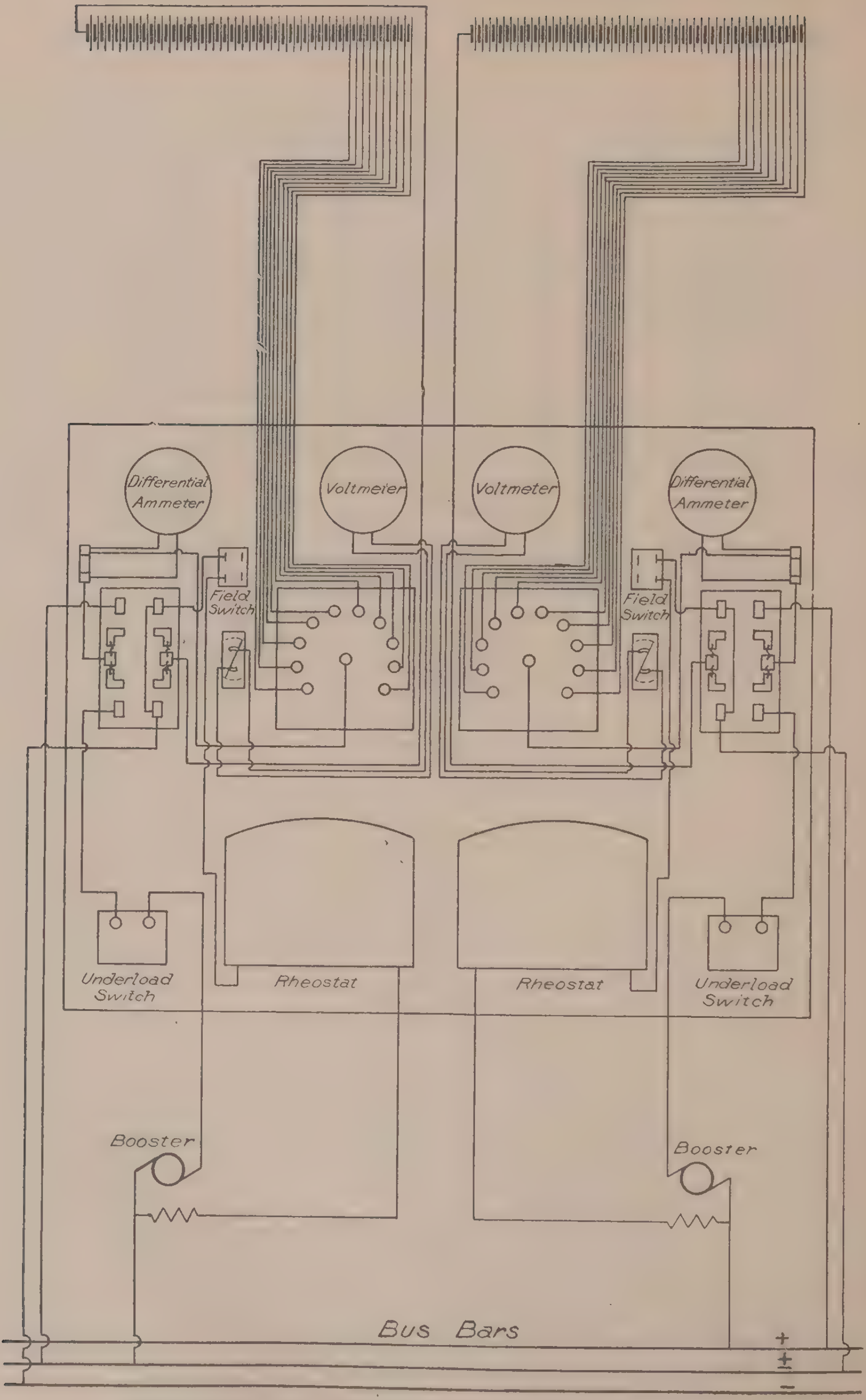


Fig. 48.

Holophane globes are made for both reflecting and diffusing the light, and they can be made to bring about almost any desired distribution with but a small amount of absorption of light. These consist of shades of clear glass having horizontal grooves forming surfaces which change the direction of light by refraction or total reflection as is necessary. The diffusion of light is effected by means of deep, rounded, vertical grooves on the interior surface of the globe. While these globes are of clear glass and absorb an amount of light corresponding to clear glass, the light is so well diffused that the filament of the lamp cannot be seen, and the globe appears as if made of some semi-transparent material. The objections to globes of this type are their high cost and the difficulty in keeping them clean.

Fig. 48 shows an enclosed arc lamp fitted with a concentric "diffuser."



Switchboard Connections for Storage Battery Auxiliary

STORAGE BATTERIES

Storage or secondary batteries, also called *accumulators*, consist of cells in which a chemical change is brought about by passing an electric current through them, thereby rendering them capable of giving back electrical energy, or *discharging*, until they return to their original chemical condition.

Ordinarily a storage battery consists essentially of two sets of plates suspended in a chemical solution. The plates are of metal or metallic oxide, and the solution is incapable of acting upon them until an electric current is passed from one set of plates to the other. This current decomposes the electrolyte, one of its ions or constituents going to one set of plates and the remaining ion or constituent to the other. Thus two chemical elements or compounds are formed, having a tendency to combine or react; and when combination or reaction occurs on closing the circuit, the energy evolved appears as an electric current, which flows in a direction opposite to that of the charging current. This flow of current continues until the cell is restored to its original condition; when this occurs, the cell is said to be *discharged.*

A *Primary Cell* is one in which electrical energy is produced by the chemical action of one or two solutions on the plates of the cell. When the solutions or plates are exhausted, they are not restored to their original condition by the passage of an electric current in the same cell; but it is possible to regenerate or recover the solutions and metal by treating them electrolytically or chemically in other vessels.

An *Electrolyte* is a chemical compound capable of acting as an electrical conductor, and while so acting, undergoes chemical decomposition. This phenomenon is called *electrolysis.*

For example, when hydrochloric acid is decomposed by electrical energy, it is decomposed into the elementary gases hydrogen (H) and chlorine (Cl). The chemical formula for this action is,

$$2HCl + \text{Electrical energy} = Cl_2 + H_2.$$

When sulphuric acid is electrolyzed, it is at first split up into hydrogen (H_2) and the radical sulphion (SO_4); the latter combines with the water of solution present and reforms sulphuric acid (H_2SO_4), oxygen being liberated. The chemical equations for the above primary and secondary reactions are:

$$2H_2O + 2H_2SO_4 + \text{Electrical energy} = 2H_2 + 2SO_4 + 2H_2O$$
$$2H_2 + 2SO_4 + 2H_2O = 2H_2 + 2H_2SO_4 + O_2$$

The modern theory of electrolysis is based upon the existence of free ions in every electrolyte. For example, a metallic salt dissolved in water is partially ionized; that is, a certain percentage is dissociated into the metal constituent and the other component part of the salt. These carry respectively positive and negative electrical charges, which are neutralized when the ions reach the negative and the positive plates of the battery. The various ions have definite velocities at which they travel or migrate through the electrolyte. The conductivity of electrolytes is entirely due to the presence of these ions, as the non-ionized portion does not conduct.

In 1802, soon after the invention of the primary cell by Volta, Gautherot demonstrated the fact that platinum wires, after being used to electrolyze saline solutions, were able to produce secondary currents. Volta, Ritter, Davy, and others noted similar effects, the phenomenon being what is commonly called *polarization*. In 1859, Planté undertook a series of experiments with the object of studying and magnifying this effect, and finally developed the Planté type of storage battery. Many of the most successful types of storage batteries of the present day are based upon Planté's invention.

Types of Storage Batteries:

Planté;
Faure;
Combination of Planté and Faure;
Non-lead.

PLANTÉ TYPES OF BATTERY

The Planté cell was originally made by placing two plates of metallic lead in a vessel containing dilute sulphuric acid. These plates were connected to an electric generator, and a current sent through the cell, which decomposed the electrolyte and oxidized the positive plate. The cell was then discharged; but the energy obtained was very small, since the action was confined to the immediate surface of the plates. By repeated charging and discharging, first in one direction and then in the other, the oxidation penetrated deeper and deeper into both plates, thus increasing the storage capacity of the cell.

The chief difficulty with the original Planté battery was the great length of time and consumption of energy required for *forming* the plates, which process, as just explained, consists in converting the surface of the plates into active materials, by repeated charging and discharging. Planté found that he could hasten this forming process by pickling the plates in dilute nitric acid, then washing them in a 10 per cent sulphuric acid solution, after which they were electrically formed. Other methods of facilitating the forming process, or increasing the active surface, are given later.

In 1881, Faure devised the method of *pasting* the lead oxide or active material directly upon the plates. This largely avoids the tedious forming process; but the plates thus produced are not so durable as the Planté elements, being more likely to disintegrate, because the paste is not an integral part of the plate.

General Principles of the Storage Battery. Any primary battery will act as a storage battery provided its chemical action is reversible. The ordinary gravity cell, for example, may be regenerated by sending a current through it in the direction opposite to that produced by it. The zinc sulphate and the metallic copper are thus reconverted into metallic zinc and sulphate of copper respectively, the chemical action being

$$ZnSO_4 + Cu + \text{Electricity} = Zn + CuSO_4,$$

which is exactly the reverse of the action in the primary cell. There are, however, practical difficulties in the continued recharging of a spent gravity cell, due to the ultimate mixture of the sulphate solutions so that the copper salt will reach the negative electrode, where it is deposited and sets up destructive local action. In some forms of primary cells, the chemical action liberates a gas that escapes, so that the action in these cases is obviously irreversible.

Chemical Action in Lead Storage Batteries. The exact nature of the chemical changes which occur in lead batteries, is not yet fully established. Planté believed the charging action to consist in the formation of peroxide of lead (PbO_2) on the positive plate, and metallic lead on the negative, which were converted into lead oxide (PbO) on both plates by the discharge. It was shown later by Gladstone and Tribe, and corroborated by subsequent investigations, that the formation of lead sulphate plays an important part.

This reaction may be represented as follows:

	Positive Plate		Electrolyte		Negative Plate
Charged Condition	PbO_2	+	$2H_2SO_4$	+	Pb
Discharged "	$PbSO_4$	+	$2H_2O$	+	$PbSO_4$
Charging Current			$\ggg\!\longrightarrow$		
Discharging Current			$\longleftarrow\!\lll$		

According to the above equations, the active material on both plates is converted into lead sulphate when the battery is discharged. The reasons for believing this to occur are: *first,* chemical analysis shows that lead sulphate exists in the discharged plate; *second,* the density of the electrolyte decreases during the discharge of the cell, corresponding to the consumption of sulphuric acid and the formation of water, as shown in the above reactions; *third,* on thermochemical grounds, the combination of lead and oxygen as lead oxide (PbO) does not evolve sufficient energy to account for the E. M. F. produced.

Storage Batteries of the Planté Type. It was noted that the first difficulty met with in the making of Planté plates was the inordinate length of time and cost of current necessary to form them; and it was also shown how Planté treated them with nitric acid to hasten this action. Other methods are used to facilitate the formation; these are tabulated as follows:

1. *Mechanical Action:* Laminated plates, made up of lead ribbons. The surface of the plate is grooved with some forming tool. Built up of lead wires, etc.
2. *Chemical:* Treating the plates in some pickling bath, to produce initial oxidation.
3. *Electrolytic:* Forming a plate of some compound of lead or an alloy, and either reducing the compound or eating the foreign matter away, leaving a porous lead plate.

Gould Storage Battery. This battery is made by the Gould Storage Battery Company, of New York, and the plates are produced by a combination of the first and third methods. The plates or blanks are placed in steel frames and given a reciprocating motion between two revolving shafts which carry grooving discs, giving the plates a surface as shown in Fig. 1. No lead is removed by this process; but the surface is ploughed up. It is then subjected to electro-chemical treatment to form the active material. The types manufactured range in size from a cell of three plates 3 inches by 3 inches, to one of 105 plates, each 15.5 inches by 31 inches; and in capacity from 5 ampere-hours in the smallest size to 17,000 ampere-hours in the largest.

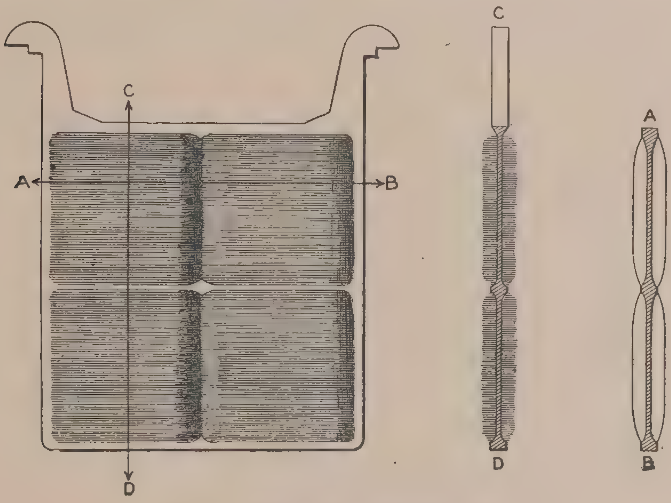


Fig. 1. Gould Storage-Battery Plate.

Bijur "High-Duty" Battery. Batteries of this type are manufactured by the General Storage Battery Company, of New York. They are made in standard sizes ranging from 6 ampere-hours to 12,688 ampere-hours, the smallest cell being made up of two plates, one positive and one negative, each 3 inches by 3 inches, suspended in a small glass jar. The largest type comprises 67 plates, each 15$\frac{3}{4}$ inches by 31$\frac{3}{4}$ inches, suspended in a lead-lined tank. Some of the standard sizes manufactured are shown in Table I.

Both positive and negative plates are of the Planté type, and are of the same general design, Fig. 2. Each plate consists of the grid or supporting frame, made up of pure lead containing a small percentage of refined antimony, producing a rigid inoxidizable supporting and conducting member for the active lead. In the openings of this rigid framework are welded gratings or *grills* of pure lead. Each grill consists of vertical strips supported by heavier horizontal

TABLE I

Data, Bijur High-Duty Battery

Type		BB	DDS	C	D		E		F		G		K		L	
Size of Plate (inches)		3x3	4⅛x8¼	3x5½	5½x5⅝		8⅛x8		10⅝x11		15¾x16		18¼x18⅝		15¾x31¾	
No. of Plates		2	2	7	5	11	5	15	7	19	11	57	21	71	19	67
Discharge Rate (in Amperes)	8 hrs.	¾	3	4.5	6	15	12	42	36	108	120	672	360	1,260	432	1,584
	5 "	1	4.2	6.5	8	21	17	59	50	151	168	942	504	1,760	605	2,218
	3 "	1½	6	9	12	30	24	84	72	216	240	1,344	720	2,520	864	3,168
	1 "	3	12	18	24	60	48	168	144	432	480	2,688	1,440	5,040	1,728	6,336
Normal Charge Rate		¾	3	4.5	6	15	12	42	36	108	120	672	360	1,260	432	1,584
Outside Dimensions of Glass Jar	Width	2⅜	3⅛	6¼	4¾	9⅛	5¼	13½	7⅜	....	....	....	....	....	....	....
	Length	3⅞	6⅛	6¼	7⅞	8⅛	9	9½	12¾	....	....	....	....	....	....	....
	Height	5⅜	12	10	10	10	12	12	16	....	....	....	....	....	....	....
Outside Dimensions of Lead-Lined Tank	Width	....	....	....	....	....	....	....	....	21¾	15⅛	54⅞	25	66½	23½	63¼
	Length	....	....	....	....	....	....	....	....	15	19¾	21½	24½	24½	22	22
	Height	....	....	....	....	....	....	....	....	17⅝	26	27½	31½	31½	48⅞	49⅞
Outside Dimensions of Glass Tanks	Width	....	....	....	....	....	....	....	....	20¼	....	....	....	....	....	....
	Length	....	....	....	....	....	....	....	....	13	....	....	....	....	....	....
	Height	....	....	....	....	....	....	....	....	18¼	....	....	....	....	....	....
Weight of Complete Cell, Incl. Acid and Containing Vessel (Pounds)		5⅝	19	25½	36	75	61	161	152	516 466	603	2,670	1,486	4,706	1,947	6,070

members which act as I-beams to stiffen it laterally, and which, with the vertical ribs, form the oxide cells. The active material is formed from the grill expanding as it grows in each of the minute oxide cells, thus locking itself in place.

The grills have no central web; and, being open structures, a through - and - through circulation of electrolyte is obtained. The grills are held on both sides by the alloy frame to which they are welded.

A suitable space is provided between each end of the grill and grid to allow for vertical elongation, while the spacing of the strips accommodates the lateral expansion. The grills are therefore free to expand in every direction, thus avoiding the tendency to set up strains in the plates, which might cause them to buckle.

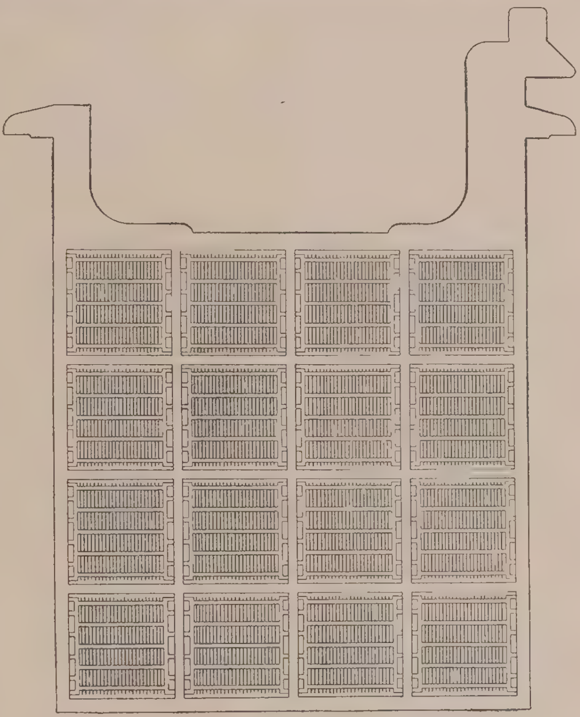


Fig. 2. Bijur High-Duty Battery Plate.

In welding the grills to the grid or frame, a heat process only is employed; no solder, flux, or foreign substance of any kind is used. Since the grill is an open structure, grown from which is a very thin layer of active material, and as this active material does not entirely close the small oxide cell, the gases evolved at high rates of charge have ready means of escape. This results in lower E. M. F.'s required for charging, and the acid diffusion thus obtained also maintains the E. M. F. when discharging at excessive rates.

With the closely adherent layers of active material in intimate contact with the metallic lead, and the absence of concentration of the electrolyte in the pores of the active mass, due to the diffusion, excessive sulphating does not occur.

The loss of negative capacity, due to shrinkage of the active material into a metallic mass, is avoided in this particular plate, by a special treatment which the plates undergo.

FAURE TYPES OF BATTERY

The difficulty with this type is the tendency to disintegrate or buckle. Various means intended to increase the permanency of adhesion of the active material have been suggested, of which the most important are as follows:

1. Plates are grooved, roughened, or *pocketed.*
2. Plates are entirely perforated, the holes being circular, or rectangular, and varying in cross-section; some have a uniform section through the grid (*A*, Fig. 3); others are contracted at the center (*B*); and again they have been expanded at the center of the grid (*C*).
3. The active materials may be enclosed in either a conducting or a non-conducting cage.
4. The plates may be made up entirely of active material.

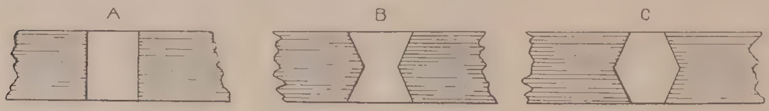


Fig. 3. Different Cross-Sections of Faure Plate Perforations.

Faure cells usually have a greater weight efficiency than those of the Planté type, because the proportion of active material may be made greater.

E. P. S. Battery. This is one of the most important of the Faure type, its name being the initials of the Electric Power Storage Company by which it is manufactured in England. It is sometimes called the "Faure-Sellon-Volckmar" cell, being based upon the work of these and several other inventors.

The plates consist of lead grids cast in an iron mould, and have the cross-section shown in Fig. 4. The later types have a thin perforated strip of lead running across each opening midway between the edges. The holes *A* in the grid are completely filled with a paste of red lead or minium (Pb_3O_4) and dilute sulphuric acid, for the positive;

while the paste for the negative consists of minium, or litharge (PbO), and dilute sulphuric acid, or a magnesium sulphate solution. These pastes are pressed into the grids and dried.

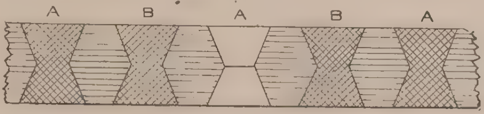


Fig. 4. Section of E. P. S. Battery Plate.

The plates are hardened in dilute sulphuric acid, after which they are ready for forming. A strong current of 48 hours' duration is required for the positive plate, and twenty-four hours is required for the formation of the negative plate. To prevent short-circuiting after the cells are set up, the plates have glass rod separators placed between them.

The E. P. S. batteries are made in many different sizes and forms, of which the L type is a good example, being used extensively in isolated plants. Data of this type are given in Table II.

TABLE II

Data, E. P. S. Accumulator, L Type

No. of Plates	Maximum Normal Charge or Discharge Rate	Capacity (Ampere-Hours)	Approximate External Dimensions			Weight Complete with Acid (Wooden Cell)
			Length	Width	Height	
7	13 amperes	130	5½ in.	13½ in. for wooden and 12 in. for glass cell	18 in. for wooden and 13½ in. for glass cell	74 lbs.
11	22 "	220	8 "			107 "
15	30 "	330	9½ "			143 "
23	46 '	500	14½ "			228 "
31	60 "	660	19 "			286 "

One of the smaller types of the E. P. S. battery is used extensively in England in electric vehicle work.

Exide Battery. This type is manufactured by the Electric Storage Battery Company, of Philadelphia, Pa., chiefly for electric vehicle duty. The plates are of the Faure type, and consist of lead-antimony grids (about 5 per cent antimony) pasted with oxides of lead.

The grid for the positive plate is of the cage type, consisting of thin vertical ribs the edges of which are flush with the faces of the plate and connected by small bars of a triangular cross-section; the bars on one face are staggered with respect to those on the other side. This finished form is then pasted up with red lead (Pb_3O_4), and formed in the usual way; the thickness of the finished plate is about $\frac{7}{32}$ inch. From this description it is evident that the plate is made up in accordance with method 3 described on page 8, the enclosing cage being of conducting material. The active material is in the form of rectangular pencils extending from the top of the plate to the bottom. The thin, flat ribs are on two sides of these pencils; and the triangular cross-pieces are imbedded in the other two sides which constitute the faces of the plates. The Exide cell is shown in Fig. 5.

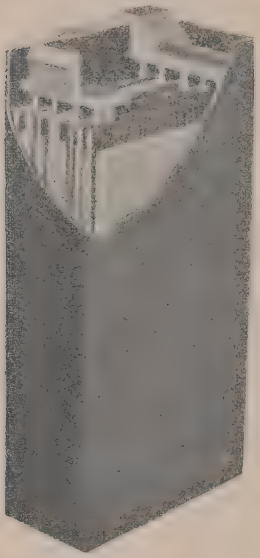


Fig. 5. Exide Battery.

The negative plate consists of a thin antimony-lead sheet, with a comparatively heavy frame of cast lead. The body of the sheet is perforated at regular points, about half an inch apart. These perforations, being made by a tool which does not remove the material, are not actual punchings; but are simply holes torn in the plate, leaving the surrounding material in ragged projections which curve back towards the sheet, forming, as it were, a series of hooks. These projections are formed on both sides of the plates.

The grid is then pasted with litharge (PbO) on both faces; it is held to the plate by the "hooks," as well as being riveted by passing through the holes which the projections surround. The thickness of this finished plate is about $\frac{3}{16}$ inch.

When assembled, the plates are placed in rubber jars of dimensions shown in Table III, and separated from one another by wooden partitions. In addition, a perforated rubber sheet is placed against the faces of the positive plates.

TABLE III

Data, Exide Cells*

Type	M. V.							P. V.			
No. of Plates.......	7	9	11	13	15	17	19	5	7	9	11
Discharge 4 Hours (Amperes)	21	28	35	42	49	56	63	12	18	24	30
Size of Plates—											
Length (inches) ...	5¾	same	same	same	same	same	same	$4\frac{13}{16}$	same	same	same
Height (inches) ...	8⅝	same	same	same	same	same	same	8⅝	same	same	same
Outside Measures of Rubber Jars—											
Width (inches)	$2\frac{7}{16}$	3¼	4¼	$4\frac{11}{16}$	$5\frac{3}{16}$	6¼	$7\frac{3}{16}$	$1\frac{13}{16}$	$2\frac{9}{16}$	3¼	4¼
Length (inches)...	$6\frac{3}{16}$	same	same	same	same	same	same	$5\frac{5}{16}$	same	same	same
Height (inches)...	11½	same	same	same	same	same	same	11½	same	same	same
Weight (lbs.)—											
Elements	15¾	20¾	25½	30¼	35	40	44¾	9¼	13¼	17¼	21½
Electrolyte	2½	3½	4½	6¼	7	8	8¾	1½	2¼	3	4½
Complete Cell......	19½	25½	31½	38½	44½	50	56	11½	17½	21½	27½

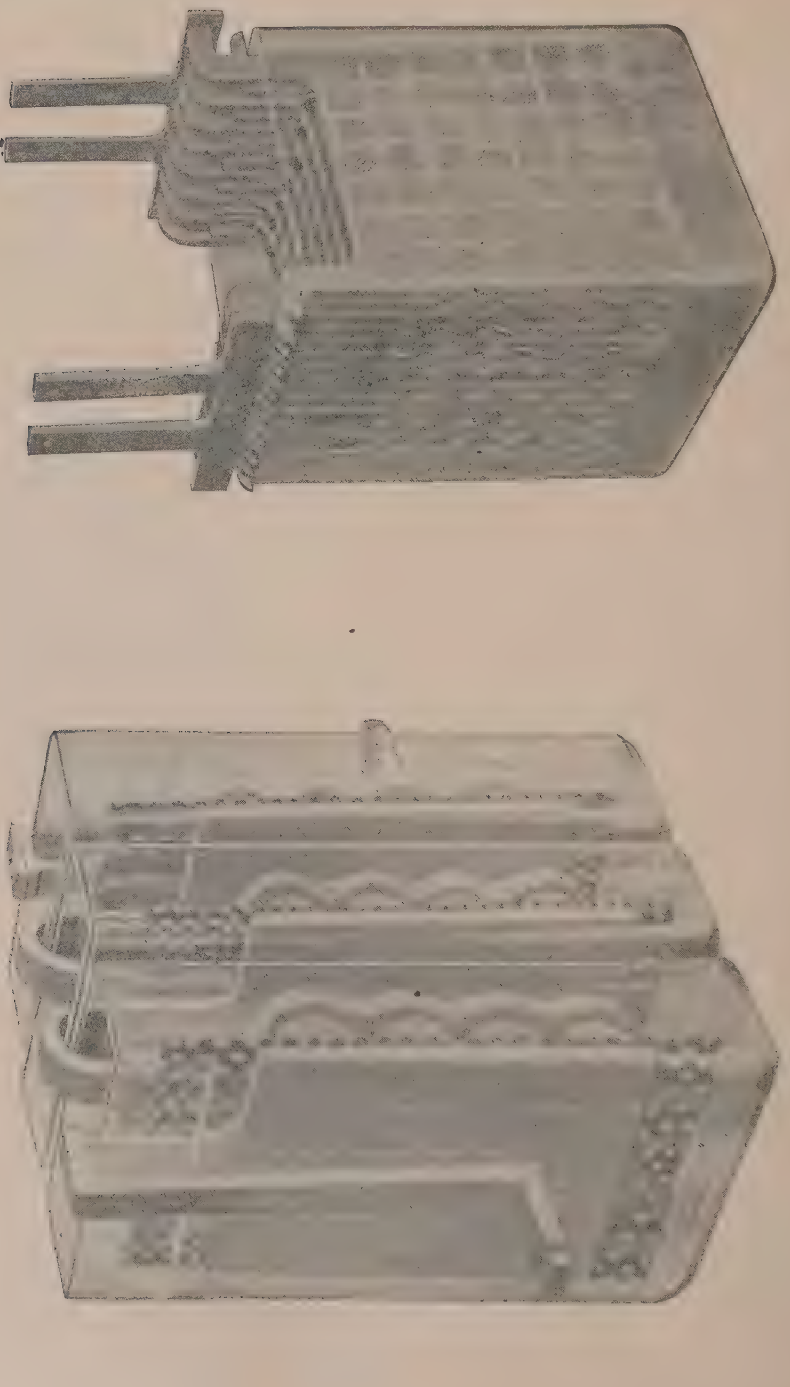
*Note.—For data on the "Express Type" of Exide cell, see literature of the Electric Storage Battery Company, Philadelphia, Pa.

The *brougham* or *hansom* battery of this type of cells consists of 44 cells of TV–9 size, having four positive and five negative plates. The weight of this outfit complete with tray is about 1,659 pounds; the capacity, 156 ampere-hours (4 hour, 39 ampere rate); the average voltage during discharge, about 1.98 volts per cell, or 87 volts for 44 in series; the total watt-hour output being therefore 13,572, or 8.18 per pound of battery complete including trays.

COMBINATIONS OF PLANTÉ AND FAURE TYPES

Chloride Battery. In the form which was manufactured until recently by the Electric Storage Battery Company and allied companies in England, France, and Germany, the Chloride Battery is a compromise between the Planté and Faure types, the positive being a Planté type and the negative of practically the Faure type.

The principal features in the manufacture of this battery are as follows: The first step is the production of finely divided lead, which is made by directing a blast of air against a stream of the molten metal, producing a spray of lead which, upon cooling, falls as a powder. This powder is dissolved in nitric acid (HNO_3) and precipitated as lead chloride ($PbCl_2$) on the addition of hydro-



B. T.—Couples in Glass Jars.

Type F—15 Plates in Glass Jar.

Fig. 6. The Chloride Battery.

chloric acid (HCl). This chloride, washed and dried, forms the basis of the material which afterwards becomes active in the negative plate. The lead chloride is mixed with zinc chloride and melted in crucibles, then cast into small pastiles or tablets about $\frac{3}{4}$ inch square and of the thickness of the negative plate, which, according to the size of the battery, varies from $\frac{1}{4}$ inch to $\frac{5}{16}$ inch. These tablets are then put in moulds and held in place by recesses, so that they clear each other by .2 inch and are at the same distance from the edges of the mould. Molten antimonious lead is then forced into the mould under about 75 pounds pressure, completely filling the space between the tablets. The result is a solid lead grid, holding small squares of active material. The lead chloride is then reduced by stacking the plates in a tank containing a dilute solution of zinc chloride, slabs of zinc being alternated with them. This assemblage of plates constitutes a short-circuited cell, the lead chloride being reduced to metallic lead. The plates are then thoroughly washed to remove all traces of zinc chloride.

In the new form of negative plate which has replaced the chloride type just discussed, the negative consists of a pocketed grid, the openings being filled with a litharge paste; it is then covered with perforated lead sheets, which are cast integral with the grid.

The positive plate is a firm grid, composed of lead, alloyed with about 5 per cent of antimony, about $\frac{7}{16}$ inch thick, with circular holes $\frac{25}{32}$ inch in diameter, staggered so that the nearest points are .2 inch apart. Corrugated lead ribbons $\frac{7}{16}$ inch wide are then rolled up into close spirals $\frac{25}{32}$ inch in diameter, which are forced into the circular holes of the plate. These spirals are electrochemically formed into active material. The process requires about thirty hours; at the same time, the spirals expand so that they tend to fit still more closely in the grids. This form of positive is that known as the *Manchester Plate.*

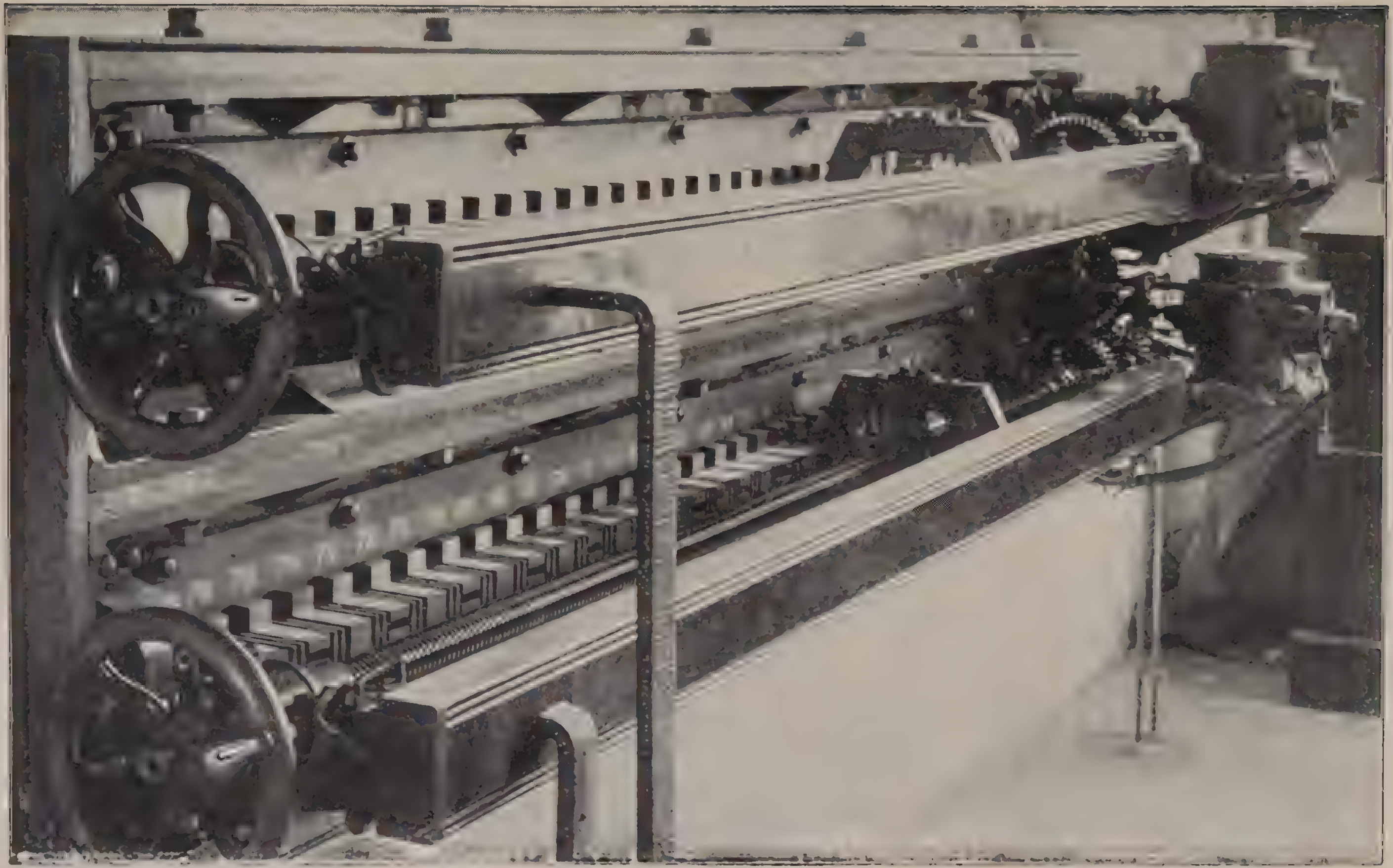
Recent types of "Chloride accumulator" are shown in Fig. 6. In setting up the cells, the plates are separated from one another by thin wood partitions having vertical grooves to facilitate the rising of the gases. These separators are stiffened by split wooden pins slipped over them. Sometimes glass tubes are used as separators.

Table IV gives data of the various types and sizes of cells. To save space, only the smallest and largest sizes of each type are given;

TABLE IV
Data, Chloride Battery

Types		B	C		BT	CT	PT	D		E		F		G		R*		H	
Size of Plate, inches ..		3x3	4, x4		3x4	5x5	8¾x5	6x6		7¾x7¾		11x10½		15½x15½		18⅝x18⅝		15½x31	
No. of Plates....		3	3	7	2	2	2	3	13	5	15	9	27	11	75	25	75	21	75
Discharge in Amperes	For 8 hrs.	⅝	1¼	3¾	¾	1½	3	2½	15	10	35	40	130	100	740	360	1,110	400	1,480
	5	⅞	1¾	5¼	1	2	4¼	3½	21	14	49	56	182	140	1,036	510	1,550	560	2,072
	3	1¼	2½	7½	1½	3	6	5	30	20	70	80	260	200	1,480	720	2,220	800	2,960
	1	....	....	....	....	....	....	10	60	40	140	160	520	400	2,960	1,440	4,440	1,600	5,920
Normal Charge Rate		⅝	1¼	3¾	¾	1½	3	2½	15	10	35	40	130	100	740	360	1,110	400	1,480
Outside Dim. of Glass Jars (inches)	Width	2½	3½	5¼	1¾	2¼	2½	3¼	11	5½	11	9	No glass jars for these large sizes.						
	Length	4	5¼	5¼	3¾	6¼	6	7⅞	8¼	9⅛	9⅛	12⅝							
	Height	6½	7¼	7¼	6¾	8	12	9½	9½	11⅜	11⅜	17							
Outside Dim. of Lead-Lined Wooden Tanks	Width	....	....	....	....	....	....	....	....	....	....	13⅜	28⅜	15⅛	69⅞	24¾	24¾	25⅛	69⅞
	Length	....	....	....	....	....	....	....	....	....	....	15	15	19¾	21½	28⅜	69⅞	21½	21½
	Height	....	....	....	....	....	....	....	....	....	....	20¼	20¼	26	27⅞	31½	32½	48¾	49¾
Weight of Cell Complete (lbs.)		5½	10½	19	3½	7½	13½	19½	64	48¾	112	175	....	....	....	....	....	....	...
Ditto. Lead-Lined Tanks...		....	....	....	....	....	....	....	....	....	....	250	615	561	3,260	1,641	4,616	1,885	5,986

* This size of cell is listed by its manufacturers on the 6, 2 and 1 hour rates; but for purposes of comparison it is brought to the same basis as the other sizes.



End Cell Regulating Switches

Minneapolis General Electric Company

but in all cases intermediate sizes are made with every odd number of plates. The capacities, weights, etc., are of course nearly proportional to the number of plates.

The smaller sizes are provided with either rubber or glass jars, and the larger ones, from F up, with lead-lined tanks.

Tudor Cell. This type is very extensively used in Europe, and to some extent in this country, although it is no longer manufactured here. The American patent rights are controlled by the Electric Storage Battery Company.

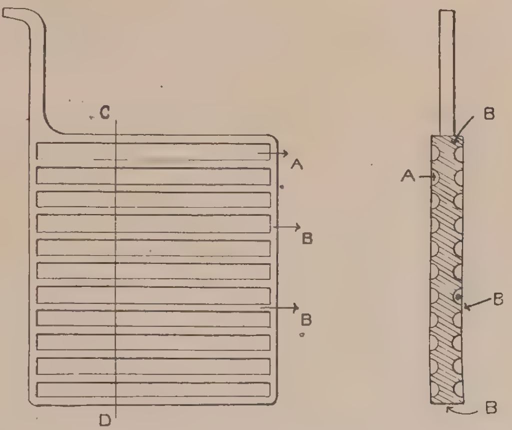


Fig. 7. The Tudor Battery Plate.

The plates consist of rolled, grooved sheets as shown in Fig. 7, *A* being the hollows or grooves into which the paste is set, and *B* the lead frame. The thickness of the plate between opposite grooves is about .12 inch for the positive and about .06 inch for the negative. The width of grooves on the positive plate is also about .12 inch, while on the negative it is about .08 inch. The grooves are first coated with a thin layer of peroxide of lead (PbO_2) by electrolysis, and then packed with the oxides as required; the plates are then rolled to *fix* the paste. This treatment of the grid with an electrolytic bath before applying the active material, is covered by United States patent No. 413,112.

TABLE V

Tudor Cells

TYPE	AVAILABLE CAPACITY	MAXIMUM CURRENT (in amperes)		DIMENSIONS OF CELLS (in centimeters)			TOTAL WEIGHT
	Amp.-Hours	Charge	Discharge	Length	Width	Height	Kgms.
I	26	6	8	12	21	35	10
V	91	21	28	30	21	35	30
X	270	54	72	42	42	55	110
XIV	630	126	168	74	42	55	230

In addition to the sizes given in this table, all the intermediate sizes are made.

Lithanode. Mr. Desmond Fitzgerald has made storage batteries with a positive plate consisting entirely of active materials made up of litharge (PbO) mixed with ammonium sulphate $(NH_4)_2SO_4$ which he pressed into the required shapes. This plate is converted into peroxide by chemical treatment. The negative consists of the ordinary lead plate. While this cell has an exceedingly high weight efficiency, it is not of much commercial importance, though used considerably in laboratory work.

It is the tendency in Europe to make the positive plate of the Planté form, and the negative of the Faure or pasted type. The reason for this is that the Planté form is hard to make; and as the activity is small on the negative, the pasted plate is good enough.

The practice in lead batteries is to make the negative plate of greater capacity than the positive, as the charging and discharging of a cell in service tends to produce or form more active material on the positive plate, whereas the negative plate is made to decrease, so that allowance for this is made as above stated. A still further allowance is made to cover this action, by always having one more negative than positive plate in a cell.

Storage Batteries Containing Metals Other than Lead. It has already been stated that almost any primary cell will act more or less as a secondary cell; as, for example, the common gravity battery. A great many have been devised in which the lead in one or both of the plates has been replaced by some other metal. For example, Reynier made the negative plate of zinc instead of lead, this zinc in discharging being converted into zinc sulphate, which dissolved in the electrolyte. The substitution of zinc for lead secures an increase in initial E. M. F. from 2.2 to 2.5 volts, and also allows of a considerable reduction in weight, since for the storage of a given amount of energy the weight of the zinc required is much less than that of the equivalent lead. A difficulty with this type of cell is the formation of *trees* of zinc on the negative plate during the charging process, which are likely to fall off or extend across to the positive plate, thus short-circuiting the cell.

Another difficulty is the difference in density of the solution between the top and bottom of the plates, the tendency being to exhaust the zinc sulphate from the upper portion of the liquid during charging. In order to avoid this trouble, the plates have been arranged horizontally, so that the density would be uniform for each plate; but the difficulty then arises that the gases which form to a certain extent in almost all batteries collect between the plates and interfere with the chemical action and the passage of the current.

A similar type of cell has been manufactured by the Union Electric Company of New York, in which the negative plates consist of thin sheet copper covered with an amalgam of zinc, and the positive plates are made up of laminæ of lead held together by leaden rivets and perforated with numerous small holes, these positives being formed by the Planté process.

Waddell-Entz Accumulator. The copper alkali-zinc primary battery of Lalande, Chaperon and Edison being reversible in action, can be used as a storage battery. Waddell and Entz have constructed accumulators on this principle. When discharged, the positive plate consists of porous copper; on charging, the electrolyte is decomposed, metallic zinc being deposited on the negative plate; the porous copper of the positive plate is oxidized, and the liquid becomes converted into a solution of caustic potash (potassium hydrate).

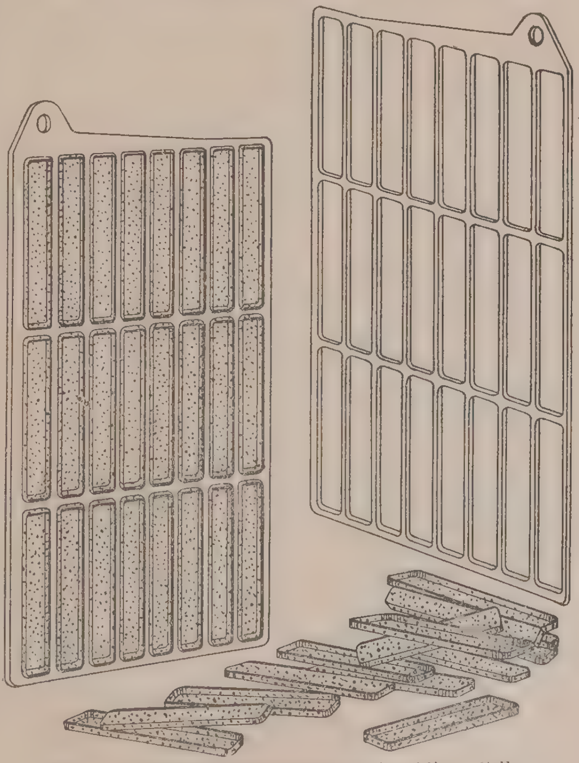


Fig. 8. Plates and Receptacles of the Edison Cell.

This storage battery was formerly used with considerable success for traction purposes; but its E. M. F. is so low, being only about .7 volt, that it would require 170–180 cells for the ordinary 110-volt electric-lighting circuit, allowing for loss of potential in the battery and conductors. This number is three times as great as is required with the lead battery. This is a serious objection to this or any other low-voltage cell.

Edison Storage Battery. The standard cells of this type are 13 inches high, 5.1 inches wide, and vary in length according to their rating, the various capacities being obtained by simply increasing the number of plates. The positive and negative plates are alike in appearance, and consist of rectangular grids, of nickel-plated iron, each about 9½ by 5 inches by .025 inch, punched with three rows of rectangular holes, eight holes to the row (Fig. 8), each hole being filled by a shallow perforated box of nickel-plated steel, the perforations being very fine, about 2,500 per square inch.

The difference between the positive and negative plates is entirely in the contents of the perforated receptacles; those for the positive plate containing a mixture of oxide of nickel and pulverized carbon, the latter being employed to increase the conductivity of the active material. The compartments of the negative plates contain a finely divided oxide of iron and pulverized carbon. When filled, these receptacles are secured to the grid by placing them in the openings of the same, and subjecting the assembled plate to a pressure of about 100 tons, which expands the pockets and fixes them firmly in the grid. A set of assembled plates as employed in a complete battery, is shown in Fig. 9.

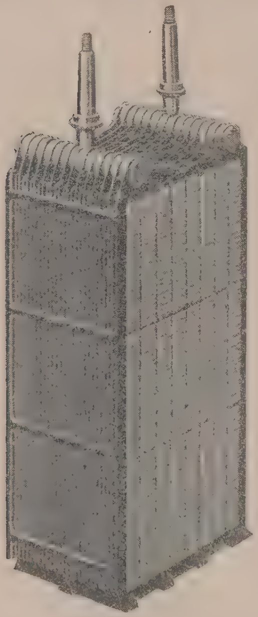


Fig. 9.
Complete Edison Cell.

The electrolyte consists of a 20 per cent solution of caustic potash, which, however, undergoes no chemical change during the process of charge or discharge, acting simply as a conveyor of oxygen between the plates. The charging current, entering at the positive plates, oxidizes the nickel compound to the peroxide state, and reduces the iron compound in the negative plates to a spongy iron mass. The containing vessel consists of nickel-plated steel; and the plates are strong individually and close together, being separated by thin strips of vulcanized rubber, thus forming a compact mass. The terminals of the plate pass through the cover of the cell, from which they are insulated by vulcanized rubber bushings.

The electrical features of the Edison cell are as follows:

Average voltage of charge at normal rate, 1.68.
Average voltage of discharge at normal rate, 1.24.

A set of charge and discharge curves of a 180-ampere-hour cell is shown in Fig. 10. This battery is rated at 30 amperes for a period of six hours. The various cells have a weight efficiency of 11.5 to 13.2 watt-hours per pound, depending upon the size. The watt efficiency under normal working conditions is about 60 per cent. The charging and discharging rates are alike, and cover wide ranges. A cell may be charged at a high rate in one hour, without apparent detriment except lowering the efficiency slightly. It is not appreciably influenced by temperature changes, and may be fully discharged to the zero-point of E. M. F., or even charged in the reverse direction, and then recharged to normal conditions, without suffering loss in storage capacity or other injury. The best results are obtained when twice as many positive as negative plates are employed; and the standard cells are made up on this basis. This type is intended especially for electric automobile service, by virtue of its high weight efficiency and its ability to endure rough mechanical as well as electrical treatment. The same qualities would also adapt it to portable electric-lighting purposes.

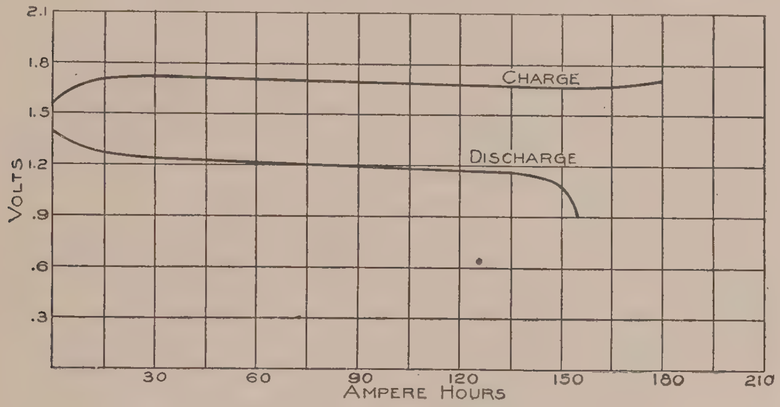


Fig. 10. Charge and Discharge Curves of Edison Cell.

MANAGEMENT OF STORAGE BATTERIES

In describing the handling of storage batteries, the various types of lead cells will be considered, as they constitute a very large majority of the cells in commercial use.

Battery Room. In the installation of a battery, the first point to be considered is its location. The room for this purpose should be dry, well ventilated, and of a moderate temperature; otherwise, not only will the evaporation of the electrolyte be excessive, but if the temperature be very high, the plates themselves will be affected and their life shortened. The floor, walls, and ceiling must be of some acid-proof material, brick or tile being preferable, and the floor so made as to drain readily, an outlet being provided to the drainage system. If the room should be an old one, and have a wooden floor, the floor should be coated with asphaltum paint, and lead trays placed below the batteries; any woodwork or ironwork in the room should be likewise treated.

The room should be sealed from the rest of the building, and located near the generating machinery and distribution switchboard, so that the copper cables may be low in cost. The windows in the battery room should be of either ground or painted glass, so that no direct rays of the sun may strike the cells, as the heat might crack the cells (glass), or increase the activity of the acid, which is not desirable.

In case the battery installation is in a cold climate, some device for keeping the electrolyte at a moderate temperature must be used.

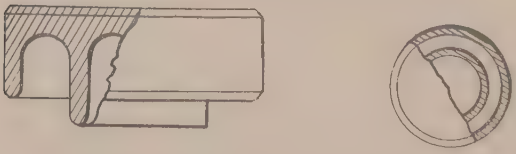


Fig. 11. Glass Insulator for Battery Support.

Setting Up the Cells. The battery is usually placed on the floor, or upon strong wooden shelves; Fig. 11 shows a form (made of glass or porcelain) adapted to cells of medium size. Iron stands are sometimes used for large and heavy cells, but they must be protected from acid fumes and drip by several coats of an acid-proof paint. Wooden stands should be varnished, painted, or soaked in paraffin for the same reason. It is important to have every cell accessible for inspection, cleaning, and removal, it being desirable to reach both sides of the cell. There should also be sufficient headroom between shelves so that the elements may be lifted out.

It is highly important that the cells be thoroughly insulated from one another, to avoid leakage of current. This is accomplished by standing each cell on four insulators of porcelain or glass of the design shown in Fig. 11. Glass is now almost universally employed because porcelain is frequently found to deteriorate gradually as a result of the action of the acid fumes.

Lead-lined tanks for 500-volt installations are usually set as follows: The floor is covered with a layer of glazed tile or brick; on this are placed two wooden stringers about 3 by 4 inches, carefully painted with asphaltum varnish or some acid-proof paint. Under each tank are set four or more insulators held in place by wooden pegs which are kept in position by pouring melted sulphur around them. Sometimes the insulators have short, threaded projections on the top, which are screwed into the bottoms of the tanks. On top of these are placed the battery tray and battery as indicated in Fig. 11.

In the case of 125-volt installations, the insulators are sometimes set directly on the tile flooring, which has been leveled by running molten sulphur under the tiling.

Oil insulators were at first used; but oil collects and holds dust, and, as dust is likely to cause leakage, they are no longer employed. For very large lead tank outfits, a double system of the supporting construction shown in Fig. 12 is used, but with individual stringers for each cell.

Glass cells are often set on wooden trays, which are filled with sand to distribute the strains and absorb the drip. Sawdust was formerly also used; but it becomes carbonized by the acid drip, and, as this is likely to cause leakage, it has been abandoned.

In connecting the cells, which are usually put in series, great care should be taken to join the positive terminal of one cell to the negative of the next, and so on. The color of the plate is the best indication of its polarity, the positive plate being a light brown when discharged and a chocolate color when charged, while the negative varies from a light to a dark slate color.

It may be noted at this point, that the nomenclature concerning storage batteries is different from that of primary cells. The positive

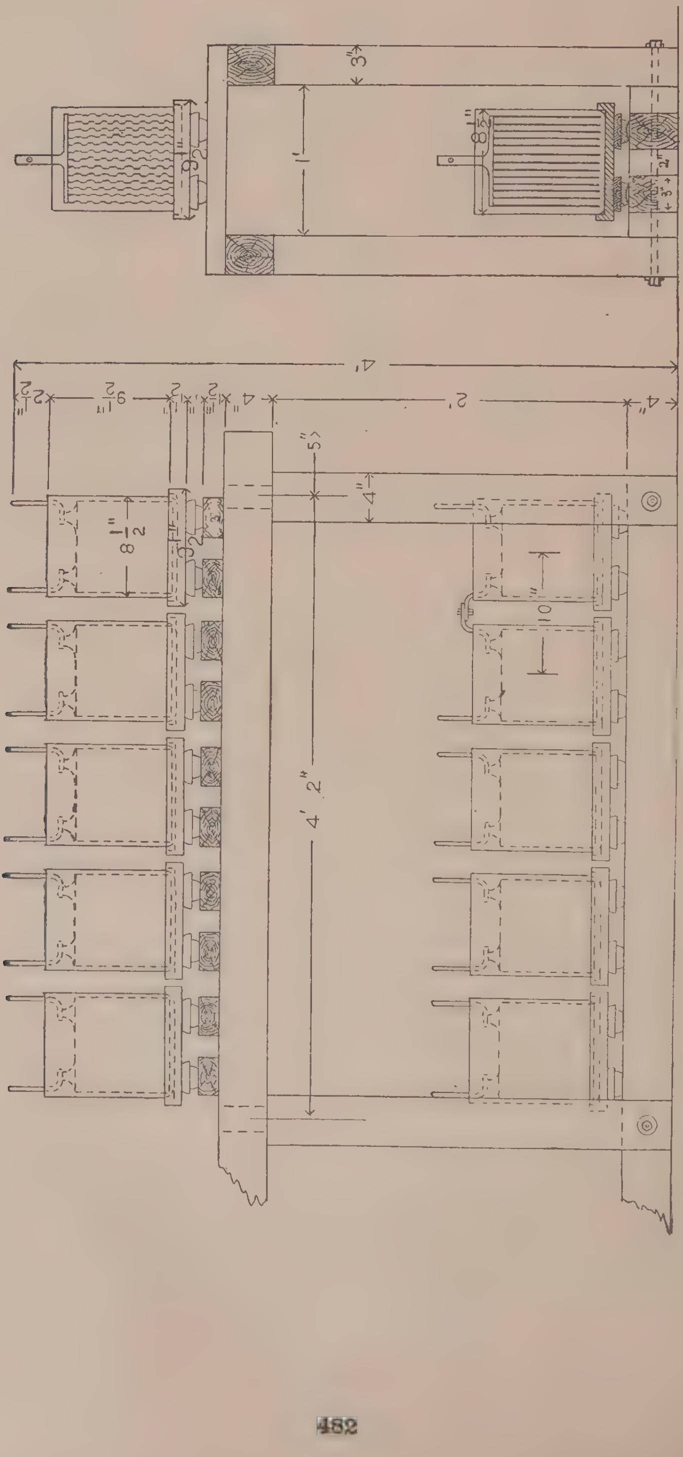


Fig. 12. Shelf Construction for Battery Support.

plate in the former is the peroxide plate (brown), and is that one from which the current flows out in discharging; whereas that would be the negative plate of a primary battery.

The positive pole or terminal in a storage battery is an extension of the positive plate, and is connected to the positive terminal of the dynamo in charging; consequently there is much less cause for confusion of terms than there is in the primary cell.

It is well to test the polarity of each cell and of the circuit, before making connections. This may be done with any form of pole-tester, or by the positive expedient of dipping the two terminals in dilute sulphuric acid, the one from which the most bubbles arise being negative. The connections should be scraped clean and screwed up very tight, then coated with acid-proof paint to avoid corrosion. The most satisfactory way to connect up a cell is to weld or *burn* the positive terminal to the negative terminal of the next cell, though soldered connections are good.

This soldering is done as follows: Two strips of lead and the terminals to be connected are very carefully cleansed; the lead strips are then clamped to the terminals, a mould placed around the joints, and molten lead poured into it.

The Electrolyte. Practice varies considerably as to the strength of solution to use. Chemically pure sulphuric acid is poured into water until its density becomes about 1.2, and then the mixture is allowed to cool before pouring it into the cells. The electrolyte *should completely cover* the plates. Cells for vehicle work use an electrolyte with density as high as 1.3. It is important to use perfectly pure acid and water, as impurities will cause local actions and ultimately destroy the plates.

It is well to remember that *water should never be poured into sulphuric acid*, as it is likely to cause the liquid to be thrown out violently.

The advantage of a strong solution is its lower resistance; but it is likely to produce the very objectionable effect of *sulphating*.

The density of the electrolyte falls immediately after filling a cell, since some of the acid is taken up by the plates; but it rises again in charging—for example, from 1.17 to 1.2. It is convenient to keep a hydrometer in several cells to observe the density of the electrolyte, not only at the beginning, but as a permanent indicator of the amount of charge and general working conditions.

The hydrometer is an instrument for determining the specific gravity of a liquid, and consists of a weighted bulb and an upright glass rod, bearing a scale, the unit point being fixed by the distance to which it sinks in pure water at 4°C. Readings above this point are for solutions of lower specific gravity than water, and those below it are for solutions of a higher specific gravity. For storage battery work, the specific gravity of the electrolyte is always between 1.1 and 1.3; hence we require only a certain portion of the scale as represented in Fig. 13.

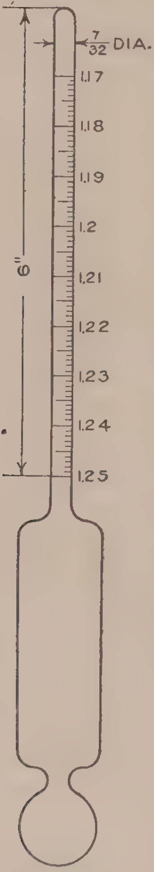


Fig. 13.
Hydrometer.

Charging. The charging should begin immediately after a new cell is filled with the electrolyte; otherwise the plates are likely to become sulphated. The first charge differs from subsequent regular charges in that it should be at a rate (lower than normal) that will not cause the temperature of the cell to reach 100°F.; but in all other respects it is the same.

Indications of Amount of Charge in a Storage Battery. There are various methods of ascertaining the amount of charge in a storage battery. The following are the indications that will serve the purpose:

1. The E. M. F. rises from 2.1 volts, at the beginning of the charging of a lead cell, after it has been discharged, to approximately 2.5 volts when fully charged, although this value may be made a trifle higher or lower, depending upon the rate of charge and temperature of cell. The rise is quite gradual, but more rapid near the beginning and end of the charge, as indicated in Fig. 14. When the cell is fully charged, the E. M. F. becomes constant, and the curve approaches a horizontal line as shown. The charging should then be stopped, as any more energy passed through the cell is simply wasted in producing gases. The external voltage is higher in charging than in discharging, because of the internal resistance of the cell and resulting IR drop, which must be overcome in charging.

The measurements of voltage should always be made when the current is flowing either in charging or discharging.

The E. M. F. on open circuit has little practical significance, since a cell, no matter how low it may have been discharged, will show about 2.1 volts after standing on open circuit a short while.

2. *If a record is kept* of the exact number of ampere-hours of charge and discharge, the actual amount of energy in the battery at any time is known, due allowance being made for leakage and other losses. For this purpose any integrating instrument, such as the Thompson recording wattmeter, may be used.

3. *The density of the electrolyte* gradually rises during the charging operation (Fig. 14), the density when charged being about .025 higher than when discharged. There is a lag in the change of the density of the electrolyte, the acid not being absorbed or given off at once by the plates; hence a little time should be allowed before taking any hydrometer reading as final. It is also advisable

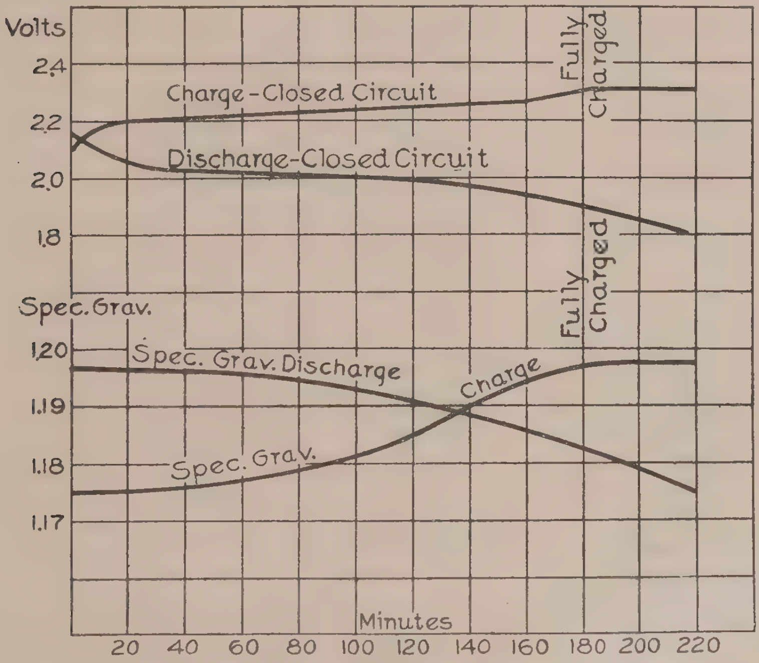


Fig. 14. Curves Showing Variations in Specific Gravity and Voltage in a Storage Battery during Charge.

to agitate the electrolyte to insure complete diffusion, as the electrolyte at the bottom of the cell is otherwise denser than at the top.

4. *Bubbles of gas are given off* freely when the battery is fully charged, since the material of the plates is then no longer able to take up the oxygen and hydrogen which tend to be set free by the electrolysis; these bubbles give the electrolyte the appearance of boiling, and often they are so fine that the liquid looks almost milky white, particularly in a cell which has not been very long in use.

5. *The color of the positive plates* varies from a light brown on active parts to a chocolate color when fully charged, and to nearly black when overcharged. The negatives vary from pale to dark slate color, but they always differ in color from the positives. This indication of the amount of charge is acquired by experience, but is quite definite after one becomes familiar with a particular battery.

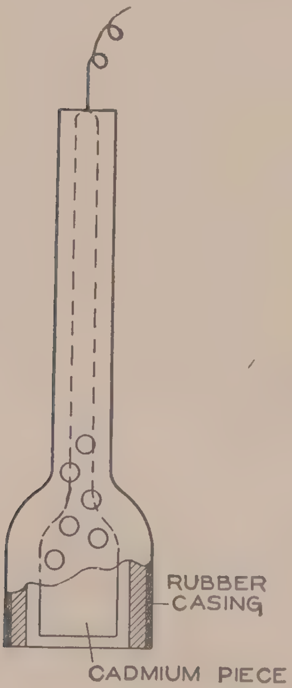


Fig. 15. Cadmium Test-Piece.

6. *Cadmium Test.* The apparatus for making this test consists of a small piece of cadmium, say $\frac{5}{8}$ by $\frac{5}{8}$ by $\frac{1}{32}$ inch, contained in a perforated hard rubber casing (shown in Fig. 15), the rubber covering being employed to prevent short-circuiting of the cell during the test (see Fig. 15). A rubber sleeve contains the conducting wire, wax being used to protect the soldered joint of copper and cadmium. Cadmium is used because it will give reliable readings of the E. M. F. of the positive and the negative plates, with respect to itself. In this way a relative condition of the battery and also of each plate can be determined.

With normal conditions of cell, when fully charged and in open circuit, the difference of potential between the positive and the cadmium piece immersed in the liquid is 2.5 volts or nearly so, and between the cadmium and the negative plates is zero or nearly so. In fact it is sufficient if the sum of the readings is about 2.5 volts.

To avoid false conclusions in making a cadmium test, hydrometer, temperature, and charge data should be noted. The cadmium test is usually made by inserting the tester at the center of the cell to get a uniform current distribution. This test gives readings the sum of which is less than 2.50 volts, when hydrometer tests, temperature, and charge data show that the cell is not fully charged. If the hydrometer, temperature, and other data show the charge to be completed, and the cadmium test gives .1 volt or more below 2.5 volts, one or more plates are defective and may be found by individual cadmium readings. For example, suppose we have a cell in which all the other conditions tend to show full charge, but the potential difference is low. A cadmium test is made; and the set of plates which shows the falling off from normal reading is the defective one, and should be examined for some of the troubles that will be discussed later.

In some cases the cadmium reading with respect to both positive and negative plates may approach zero; this is caused by a short circuit in the cell, which should be found and removed immediately.

In practice it is advisable to have the cadmium wet before the test is made, as the readings increase when cadmium is first placed in the electrolyte. The simplest way to accomplish this is to keep the cadmium tester in a beaker of distilled water when not in use. All foreign matter should be carefully removed from the cadmium, as it might affect the results. If gas bubbles collect on the cadmium, they should be taken off, as they tend to lower the readings.

The proper rate of charge depends upon the size and type of cell, and is usually specified by the manufacturer in each case, since it is merely an empirical fact, being determined by the construction of the plates.

The current for charging is ordinarily obtained from a direct-current dynamo, but any other direct-current source may be employed. The potential required for charging must exceed that of the battery, which, during the operation, acts as a counter-E. M. F., the expression being $I = \frac{P-e}{R}$, in which I is the current, P the potential applied to battery terminals, e the counter-E. M. F., and R the internal resistance of the cell. Usually P is 5 to 10 per cent greater than e, in order to cause the necessary charging current to flow through the resistance R of the cell.

In practice, P is regulated until the required charging current I is obtained.

The above equation, put into form of $R = \frac{P - e}{I}$, enables the internal resistance R to be calculated; but, as this varies considerably with the temperature and with different states of charge, its exact value is not often considered.

Another form of the above equation, $e = P - IR$, shows that the true E. M. F. of the battery is less than the charging voltage by an amount equal to the product of the charging current and the internal resistance. Conversely, in discharging, the total E. M. F. of cell is greater than the difference of potential P between its terminals, by the same amount; that is, $e = P - IR$. Hence it is necessary to know I and R, in order to find the real E. M. F. of cell. This applies to each individual cell, as well as to the entire battery, and is important in determining the amount of charge or working condition of a particular cell.

If the charging voltage P be kept constant, it is evident from the above equations that the current I will gradually decrease, since the C. E. M. F. or e of the cell steadily rises as shown in Fig. 16. This effect is counteracted somewhat by the fact that the internal resistance R also diminishes, owing to the density of the electrolyte increasing. This gradual reduction in the strength of the charging current is considered desirable by some authorities, since it enables the cell to take a greater charge than if the current were maintained

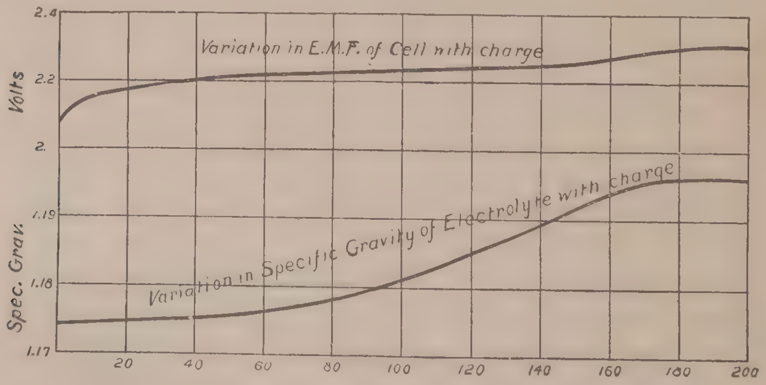


Fig. 16. Curve Showing Increase of E. M. F. in a Charging Cell.

at full strength. On the other hand, this diminishing charge makes it difficult to keep account of the exact number of ampere-hours supplied to the cell; hence, in ordinary commercial work, it is considered simpler to charge with a constant current, and if it is desired to keep the cell temperature down, the current is decreased near the end of the charge. The charging operation may be continued until the battery is fully charged as shown by the indications already stated. Since most types of cells are not injured by a slight overcharging at a moderate rate, it may even be carried a little beyond the charged point, as it tends to remove sulphating. A considerable overcharge should be avoided, as it causes excessive formation of gas bubbles in the active materials and is likely to heat the cell and even to cause disintegration and buckling of the plates.

Discharging. A storage battery is in most cases discharged within a few hours after being charged, as, for example, in electric lighting, when the engine and dynamo are run during the day for charging the battery which supplies current to the lamps during the night. But a portable battery for feeding lamps or a vehicle battery might be required to retain its charge for several days. The loss of charge in any battery standing on open circuit is about 25 per cent in one week, but for one day or less it is quite small.

Even when the discharge occurs immediately, the average voltage and the ampere-hours obtained are less than for the charge, as explained under "Efficiency." The loss referred to is additional, depending upon the time.

The operation of discharging is naturally the converse of charging, the changes which have been described as occurring in the latter take place also in the former, but in the reverse order. The normal rate of discharging is usually equal to that of charging, but may be somewhat greater. In some cases it is necessary to discharge at higher rates; but, by so doing, a percentage of the capacity in ampere-hours is sacrificed.

For example, a cell whose normal or eight-hour discharge rate is 100 amperes, can easily be discharged at 400 amperes for one hour, but only 50 per cent of the cell's capacity in ampere-hours is obtained at the latter rate. Under these latter conditions, there is not a large loss of energy, as is shown by the fact that to recharge a cell thus discharged requires only about 50 per cent of the normal charge.

TABLE VI

Percentage of Capacity Variation at Different Discharge Rates

Rate in Hours	Percentage of Capacity at 8-Hour Rate		
	Planté	Planté (+) Faure (—)	Faure
8	100	100	100
7	99	97	96
6	96½	93½	92
5	93	89	86
4	88	83	80
3	80	75	72
2	70	65	61
1	55	50	40

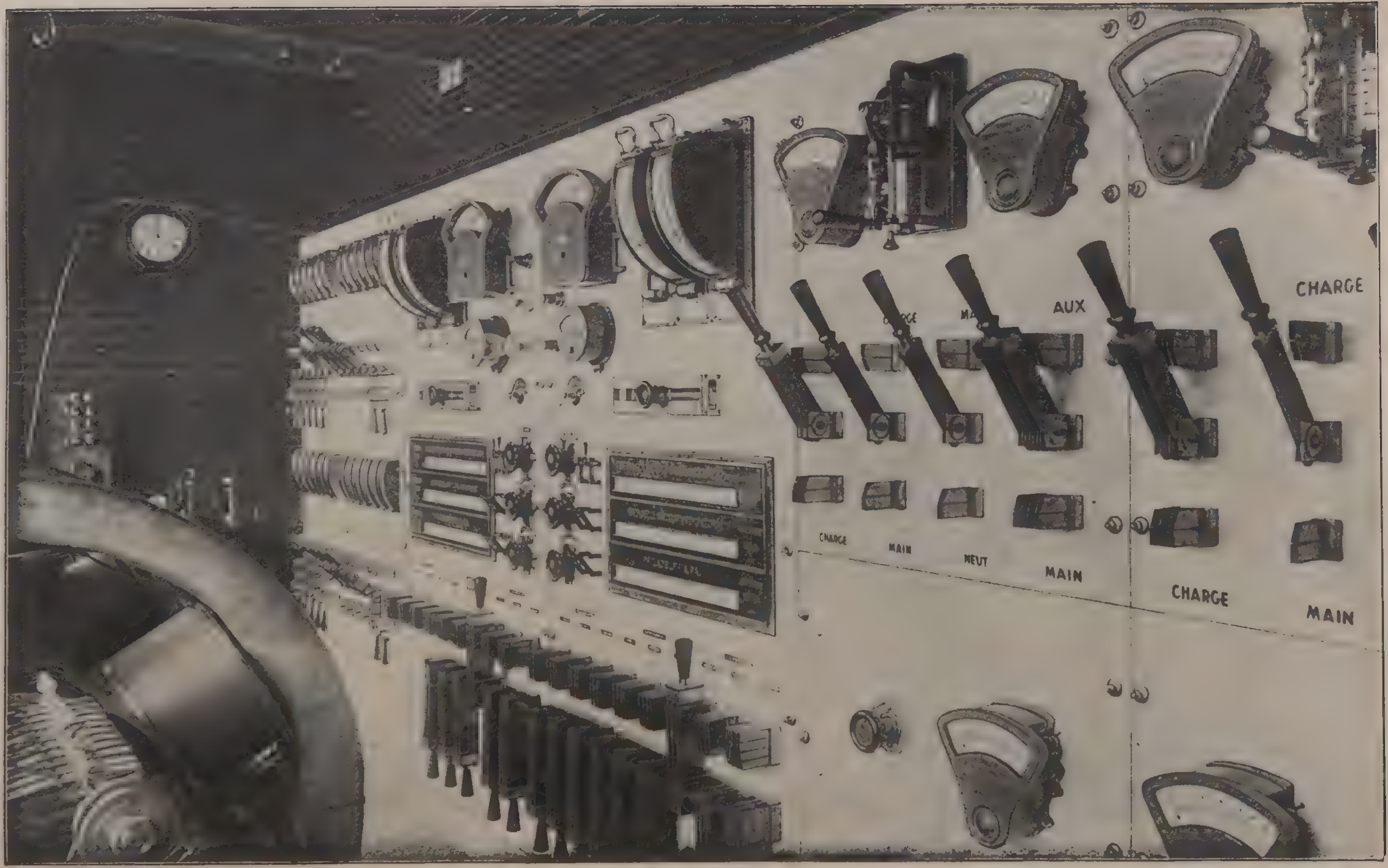
An excessive discharge rate is injurious to most types of storage-battery plates, since it tends to disintegrate the plates, and abnormally heats the electrolyte, which hastens the disintegration. It is therefore advisable to protect the battery with fuses or a circuit-breaker.

A storage battery *should never be discharged completely*, as it is very likely to become sulphated or otherwise injured; and moreover the voltage falls so rapidly towards the end of discharge that the current would be of no practical value. The limit of discharge is usually considered to be the point at which the voltage drops to 1.75, though when cells are used at the one-hour rate the limit of discharge is 1.6 volts.

A battery should never be allowed to stand in a discharged condition, but should be recharged immediately.

The charge usually left in a storage battery is from 10 to 30 per cent of the total capacity, depending on the rate of discharge; but this involves no considerable loss of energy or efficiency, since it remains in the battery each time, and the charging begins at that point.

Efficiency of Storage Batteries. The efficiency of any apparatus is the ratio between output and input. In a storage battery it is the ratio of the amount of discharge to what is required to bring the battery back to its original condition after a discharge.



Storage Battery Switchboard

Detroit Edison Company

The *ampere efficiency*—or, more properly, the *ampere-hour efficiency*—which is the ratio of current in ampere-hours drawn from the battery to current in ampere-hours put into the battery, is quite different from the *watt-hour efficiency*. The latter is the *real efficiency* since it considers the energy, and includes the voltage as well as the ampere-hours. The former may be used either through ignorance or intention to give a false idea, since the ampere efficiency is often 15 per cent higher than the watt efficiency.

Another difficulty is the fact that it is possible to obtain an apparent efficiency of over 100 per cent from a storage battery. Since a certain amount (about 25 per cent) of charge is always left in the cell, it is possible to draw more ampere-hours than were put in during the last charge, by simply discharging the cell more than usual.

This matter has been investigated by Ayrton, who says:

> "If an E. P. S. accumulator be over and over again carried around the cycle of being charged up to 2.4 volts, and discharged down to 1.8 per cell, the charging and discharging currents being the maximum allowed by the makers—namely, .026 ampere per square inch of surface in charging, and .029 ampere per square inch in discharging—the working efficiency thus obtained may be 97 per cent for the ampere-hours, and 87 per cent for the watt-hours. If, on the contrary, the cell be constantly charged up before being tested, then for the first few charges and discharges between the above limits, and with the same current density in charging and discharging, even the energy efficiency may be as high as 93 per cent; whereas, if the accumulator has been left for some weeks, then, although it was left charged, the energy efficiency for the first few charges and discharges will be as low as 70 per cent."

In general practice it has been found that the watt-hour efficiency of storage-battery plants, when in good condition, varies from 75 to 80 per cent. For instance, referring to the battery plant at the Edison Electric Company station in Boston, a series of tests made there show the battery installation to have an efficiency of 75 per cent.

Depreciation of Accumulators. The depreciation is claimed to be as low as 4 or 5 per cent per annum; but 7 per cent is a safer allowance to cover depreciation and renewals extending over long periods of time. During the first few years the depreciation may be practically nothing; but after five or ten years it will be considerable. These statements apply to *stationary* batteries in central stations or isolated plants. For *traction* or *automobile* service, which is much more severe, the life of storage batteries in some instances has not exceeded six months; and 3,000 to 5,000 miles total run is considered a good result in actual practice. For either stationary or vehicle storage batteries, the life of the positive plates is only half as great as that of the negatives. The figures given are based upon an average of the two.

It has been the practice of several storage battery manufacturers to insure their stationary battery equipments for 6 per cent per annum of their first total cost. This insurance is a maintenance contract calling for inspection and any repairs necessitated through normal use of cells.

TROUBLES AND REMEDIES

The most serious troubles which occur in storage batteries are *sulphating*, *buckling*, *disintegrating*, and *short-circuiting* of the plates. These can usually be avoided, or cured by proper treatment if they have not gone too far.

Sulphating. The normal chemical reaction which takes place in storage batteries is supposed to produce lead sulphate ($PbSO_4$) on both plates when they are discharged, their color being usually brown and gray, as already stated. But under certain circumstances a whitish scale forms on the plates, probably consisting of $Pb_2 SO_5$. Plates thus coated are said to be *sulphated*. This term is therefore somewhat ambiguous, since the formation of a certain proportion of ordinary lead sulphate ($PbSO_4$) is perfectly legitimate; but the word has acquired a special significance in this connection.

A plate is inactive, and practically incapable of being charged, when it is covered with this white coating or sulphate, which is a non-conductor.

The conditions under which this objectionable sulphating is likely to occur are as follows:

(*a*) A storage battery may be overdischarged—that is, run below the limits of voltage specified—and left in that condition for several hours.

(*b*) A storage battery may be left discharged for some time, even though these limits have not been exceeded.

(*c*) The electrolyte may be too strong.

(*d*) The electrolyte may be too hot (above 125° F.).

(*e*) A short circuit may cause sulphating, because the cell becomes discharged (on open circuit), and, when charging, it receives only a low charge compared with the other cells of the series. A battery may become overdischarged or remain discharged a long time, on account of leakage of current due to defective insulation of the cells or circuit; or the plates may become short-circuited by particles of the active material or foreign substances falling between them.

Sulphating may be removed by carefully scraping the plates. The faulty cells should then be charged at a low rate (about one-half normal) for a long period. In this way, by fully charging and only partially discharging the cells for a number of times, the unhealthy sulphate is gradually eliminated. When the cells are only slightly sulphated, the latter treatment is sufficient without scraping; when the cells are very badly sulphated, the charge should be at about one-quarter the normal rate for three days.

Adding to the electrolyte a small quantity of sodium sulphate, or carbonate, which latter is immediately converted into sodium sulphate, tends to hasten the cure of sulphated plates by decomposing or dissolving the unhealthy sulphate. This is not often used in practice, as a cell must be emptied and thoroughly washed, and fresh electrolyte added after the plates have been restored to their proper condition, before the cell can be used to advantage.

Sulphating not only reduces the capacity of lead storage batteries, but also uses up the active material by forming a scale which falls off or has to be removed. It also produces the following troubles:

Buckling. Buckling or warping of a plate, is caused by uneven action on the two surfaces; for example, a patch of white sulphate on one side of a plate will prevent the action from taking place there, so that the expansion and contraction of the active material on the other side, which occurs in normal working, will cause the plate to buckle. This might be so serious that it would be impossible to straighten the plate without breaking or cracking it; but, if taken in time, this may be accomplished by placing the warped plate between boards, and subjecting it to pressure in a screw or lever press. Striking the plate is objectionable, because it cracks or loosens the active material; but, if it should be necessary to straighten a plate in this way, a wooden mallet should be used very carefully, with flat boards laid under and over the plate. Buckling may be caused by an excessive rate of charging or discharging, as well as by sulphating.

Disintegration. Some of the material may become loosened or entirely separated from the plates, as a result of various causes.

The chief of these is sulphating, which forms scales or blisters that are likely to fall off, thus gradually reducing the amount of active material and the capacity of the cell. Buckling also tends to disintegrate the plates. Contraction and expansion of the active material take place in normal working, and are increased by excessive rates or limits of charging and discharging. This constitutes another cause of disintegration, particularly in plates of the Faure type containing plugs or pellets of lead or lead oxide paste.

The fragments which fall from the plates not only involve a loss of material, but are also likely to extend across or gather between the plates, and cause a short circuit.

The positive plates are far more susceptible to and injured by these troubles than the negatives. The former are also more expensive to make; therefore it is to them that special attention should be directed in the management of storage batteries.

Short-Circuiting. Short-circuiting of a cell may be caused by conditions previously stated, and also by the collection of sediment at the bottom of the containing cell. The short-circuiting caused by the dropping in of foreign matter, or the bridging of the active materials, is prevented by the use of glass, rubber, or wooden separators.

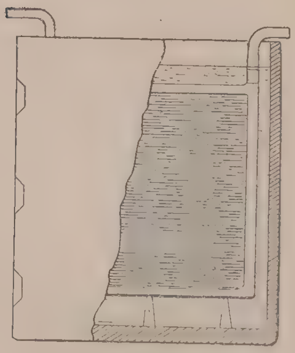


Fig. 17. Glass Frame Support Used to Prevent Short-Circuiting by Sediment.

The short-circuiting of plates by the formation of sediment is prevented, or the chances of it are decreased, by raising the plates so that they clear the bottom of the containing cell. In small batteries this clearance is about an inch; in very large cells it is considerable, being about 6 inches; and large-sized plates, on account of their weight, are supported at the bottom by glass frames running lengthwise through the cell, as shown in Fig. 17.

This sediment should be watched carefully; and when it reaches a depth of 1 inch or more at the center of the cells, it should be removed. The usual method is to take out the plates, siphon the electrolyte off carefully, and then flush out the tanks until all the sediment is removed. If siphoning cannot be resorted to because of the absence of drop, a pump may be used, either of glass or of the bronze rotary type.

Troubles from Acid Spray. A storage battery gives off occasional bubbles of gas at almost any time or condition; but when nearly charged, the evolution becomes more rapid. These bubbles, as they break at the surface, throw minute particles of acid into the air, forming a fine spray which floats about. This spray not only corrodes the metallic connections and fittings in the battery room, but is also very irritating to the throat and lungs, causing an extremely disagreeable cough.

Glass covers are sometimes placed over cells to prevent the escape of fumes; but this is not advisable, as the glass becomes moist and will collect dust, thus forming a conducting surface over the cell.

Attempts have been made to do away with this spraying by placing an oil film (thin layer of oil) over the electrolyte; but this has the objection of interfering with hydrometers; in addition, it sticks to the surface of the plates when they are removed, and interferes with their conductivity on replacing them.

Another plan consists in spreading a layer of finely granulated cork over the surface of the liquid; but while this does not interfere with the hydrometer, it makes the cell look dirty.

The general practice is to depend almost entirely upon ventilation to get rid of the acid fumes; in fact, even forced ventilation is used. A blower forces fresh air into the room, which is provided with a free exhaust.

In connecting up the cells, it is advisable to use lead-covered copper cables, and to paint all connections with an acid-resisting paint, as these coverings protect the copper and prevent the formation and the dropping of copper salts into the cell.

Purity of the Electrolyte. This is very important, and great care should be taken to insure it. The electrolyte may have nitric acid present when formed (Planté) plates are used; and some chlorine, when Chloride negatives are used. In addition, iron may be present, due to the water or acid if the sulphuric acid is made from iron pyrites; it may also be present owing to the corrosion of iron fittings near the cells, some of the scale falling into the electrolyte. Similarly, some of the copper salt formed from the connections by this corrosive action may fall into the cell. Mercury may also be present as a result of the breakage of hydrometers or thermometers.

Other foreign substances might be present, but those named are the most harmful. Nitric acid, even in exceedingly small quantities, will cause disintegration of plates, as the supporting material is destroyed. Chlorine has a similar effect. Iron, mercury, and copper produce local action, and thus decrease the efficiency and ultimately the life of the cells. The electrolyte should be tested about once a week for these impurities; and if any of them are present, it should be drawn off and renewed. If nitric acid is present, it is even advisable to flush the cell with pure water.

TESTS

1. **Test for Chlorine.** Take a sample of the electrolyte, acidulate with nitric acid, and add a few drops of silver nitrate solution. If a curdy white precipitate forms, which is soluble in ammonium hydrate, chlorine is present in some of its compounds.

2. **Test for Iron.** Iron may appear in one of two forms, namely, ferrous or ferric salts. A small sample is taken, and some concentrated hydrochloric acid added, and then some potassium ferric cyanide; if a heavy blue precipitate forms, ferrous iron is present; if in very minute quantities, a deep blue-green discoloration results.

3. **Test for Ferric Salts.** To a sample of the electrolyte, add some hydrochloric acid and a few drops of ammonium thiocyanite; if a blood-red solution or precipitate is the result, ferric salts are present.

4. **Test for Copper.** To a sample of electrolyte, an excess of ammonium hydrate is added; if a rich blue solution is the result, copper is present. It is advisable to check the test by taking another sample and adding some potassium hydrate to it; if a blue precipitate is found which turns black upon boiling, it is additional proof of the presence of copper.

5. **Nitric Acid or its Compounds.** As these are injurious, even in very small quantities, it is advisable to make the following test, which is very sensitive: Some diphenylamine in concentrated sulphuric acid is added to the sample; if a deep blue color is the result, nitrates or nitrites are present.

6. **Test for Mercury.** Mercury may be present in two forms, mercurous or mercuric compounds. The *mercurous* compounds give a black precipitate with lime water, and a greenish precipitate with potassium iodide. The *mercuric* compounds give a yellow precipitate with lime water, and a red or scarlet precipitate with potassium iodide.

On account of possible difficulties with these various impurities, the following are recommended:

1. Test every carboy of sulphuric acid before using.
2. Concentrated sulphuric acid should not be kept around, as it may be used by mistake, which would ruin the plates.
3. Only distilled water from carboys should be used, and not from barrels, as in the latter case it may be contaminated by organic matter.
4. Water from the city mains is never to be used unless the amount of impurities which it contains is very small.
5. When testing with hydrometer for specific gravity, the battery should be fully charged, and tests *always made at the same temperature, or temperature changes should be corrected for,* because the specific gravity of the electrolyte falls with increase of temperature. The specific gravity changes due to temperature are given in Table VII.

TABLE VII

Specific Gravity of Dilute Sulphuric Acid at Various Temperatures

Temperatures	30° F.	40° F.	50° F.	60° F.	70° F.	80° F.	90° F.	100° F.	110° F.
Sp. gr.	1.1593	1.1562	1.1531	1.1500	1.1469	1.1438	1.1407	1.1376	1.1345
"	1.2096	1.2064	1.2032	1.2000	1.1968	1.1936	1.1904	1.1872	1.1840
"	1.2620	1.2590	1.2530	1.2500	1.2470	1.2440	1.2410	1.2380	1.2350
"	1.3090	1.3060	1.3030	1.3000	1.2990	1.2940	1.2910	1.2880	1.2850
"	1.3620	1.3580	1.3540	1.3500	1.3460	1.3420	1.3380	1.3340	1.3300
"	1.4144	1.4076	1.4048	1.4000	1.3952	1.3904	1.3856	1.3808	1.3768

Putting the Battery out of Commission. If, for any reason, the battery is to be but occasionally used, or the discharge is to be at a very low rate, a weekly freshening charge to full capacity at normal rate should be given.

It frequently happens in practice that a storage battery equipment is put out of commission for a lengthy period (for instance, in most summer or winter resorts, the battery may be used for one-half of the year only). In such cases the procedure is as follows: First give the battery a complete charge at normal rate, then siphon off the electrolyte into carefully cleaned carboys (as it may be used again); and, as each cell is emptied, *immediately* refill it with pure water, to prevent the charged negative from heating in the air, as this would result in loss of capacity. When the acid has been drawn from all cells and replaced with water, begin discharging the battery, and continue until the voltage falls to or below one volt per cell at normal load (rate); when this point has been reached, the water should be drawn off. In this condition the battery may stand without further attention until it is to be put again into service; and to do this, proceed in the same manner as when the battery was originally put into use.

If, during discharge, when water has replaced electrolyte, the battery shows a tendency to get hot (100°F.), add colder water.

COMMERCIAL APPLICATIONS

The function of a storage battery is to receive electrical energy at one time or place, and to give it out at some other time or place. The principal uses are the following:

1. To furnish portable electrical apparatus with power.
2. To make up for fluctuations, and thus steady the voltage and load on the generator.
3. To furnish energy during certain hours of the day or night, and enable the generating machinery to be stopped.
4. To aid the generating plant in carrying the maximum load (peak), which usually exists for only an hour or two.
5. To make the load on engines or prime movers more uniform, by charging the battery when the load is light.
6. To transform from a higher to a lower potential by charging the cells in series, and discharging them in parallel, or *vice-versa*.
7. To subdivide the voltage, and enable a three- or a five-wire system to be operated from a single generator.
8. To supply current from local centers or substations.
9. To supply current to electrically-driven vehicles.
10. As sources of current in telephone and telegraph systems.
11. For car-lighting purposes.
12. As sources of constant potential and current in electrical laboratories.

Portable Storage Batteries. The storage or the primary battery is practically the only means of supply for portable electric lamps or for those not connected to a dynamo even when they are not portable.

The various manufacturers furnish portable forms of storage batteries. The Gould Storage Battery Company's portable battery

(Fig. 18) is arranged in a case made as a hard rubber jar, lead-lined box, or glazed earthenware jar, over which is placed a rubber gasket, and then a wooden cover clamped in place by U-shaped straps passing around the containing vessel. For ventilation in charging, the cover has threaded holes, which, when the battery is in use, are closed with hard rubber stoppers. The usual number of cells in a case is from one to five, although they are made up in larger numbers if desired. The batteries are rated at 2 volts per cell.

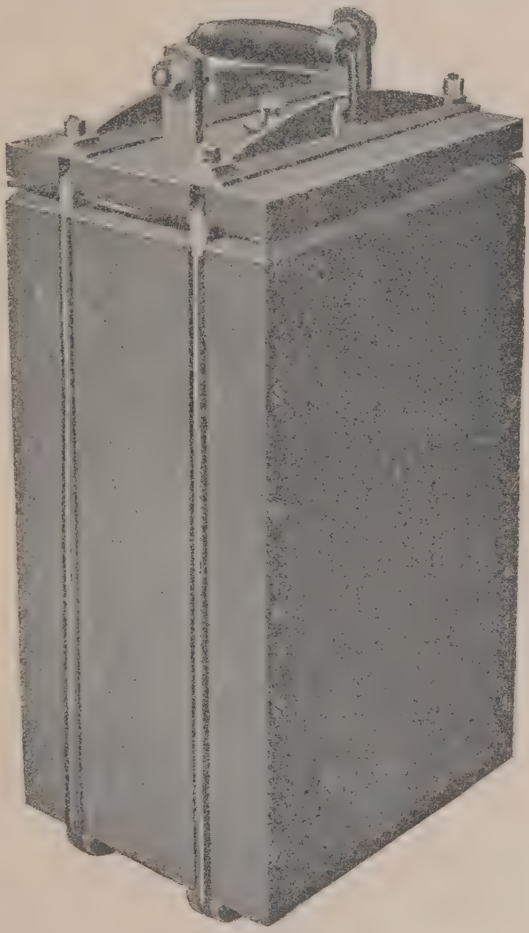


Fig. 18. Gould Portable Storage Battery.

A serious objection to portable storage batteries is their great weight. For example, a standard size weighing 100 lbs. yields 5 amperes at ten volts, or fifty watts, for ten hours—just enough to feed a 16-candle-power lamp. The total discharge is 500 watt-hours or two-thirds of one horse-power-hour. The special forms of battery used in automobiles give about twice this output for the same weight.

This weight is almost prohibitive to portability, except for automobiles, railway train lighting, and special purposes.

Portable batteries, for example, are used for feeding small motors, lamps, etc., for medical or dental purposes, in which cases their weight is not a serious difficulty, in view of the importance of the work and the small amount of energy required. Another special field for very small batteries is the theatrical application, for which they are carried by performers. Storage batteries are also extensively used as sources of power to drive small fan and kinetoscope motors.

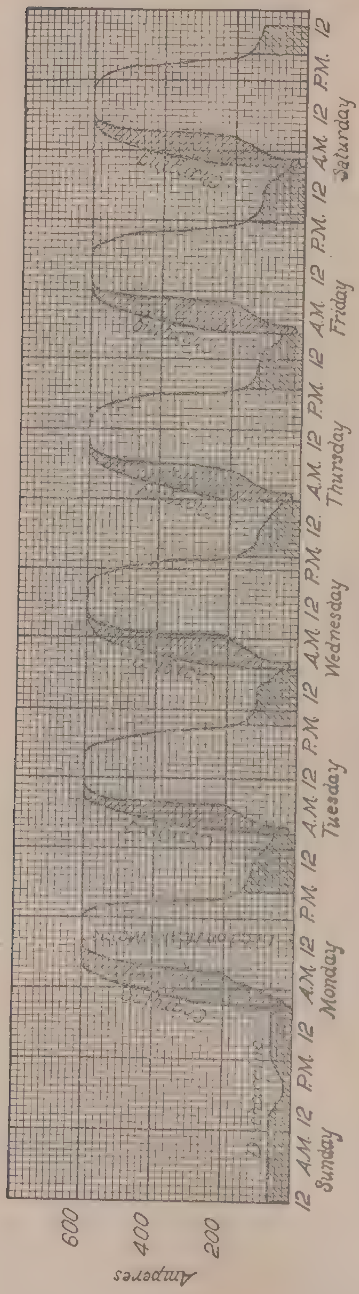


Fig. 19. Load Curve of Astor Building, New York City.

Storage Batteries for Preventing Fluctuations due to unsteadiness in the driving power or in the load, as with elevators, are often applied successfully. A dynamo driven by a gas engine for example, may vary periodically in speed because of the explosive action of the gas in the cylinder; and a battery connected in parallel with the dynamo will have the effect of steadying the voltage. A storage battery is generally installed in connection with a small gas-engine or steam-engine lighting plant, to enable the engine to be stopped for a considerable portion of the time, and thus save labor and attention, in which case the battery may also act to prevent fluctuations. A windmill electric-lighting plant must have an accumulator or some other means of storing energy, not only to eliminate fluctuations in speed, which are continually occurring, but also to bridge over the considerable periods of calm weather.

To Furnish Energy during Certain Portions of the Day or Night. In almost every electric-lighting plant, there are long periods during the day and late at night when the number of lamps lighted is so small that it may not pay to run the generating machinery.

For example, Fig. 19 is a load diagram showing the weekly output of the electric plant of the Astor Building in New York City. The generator plant runs from 3 a.m. to 8 p.m. each day, the battery being charged from 3 a.m. to 11 a.m.; and when the generating plant is shut down at 8 p.m. the battery carries the entire load from then until 3 a.m., when the plant is started up again. Saturday nights the plant is shut down at eight o'clock, and the battery furnishes all the power required from then until Monday morning at 3. This enables the plant to be operated by two gangs or shifts, practically no labor being required for the remaining seven hours, as the battery carries the load, and the machinery is stopped entirely all day Sunday, giving a stretch of thirty-one hours once a week, and seven hours each night for cleaning and repairs. In a hotel or residence, or on board a yacht, it may be desirable to stop the machinery and avoid the vibration and noise during the night.

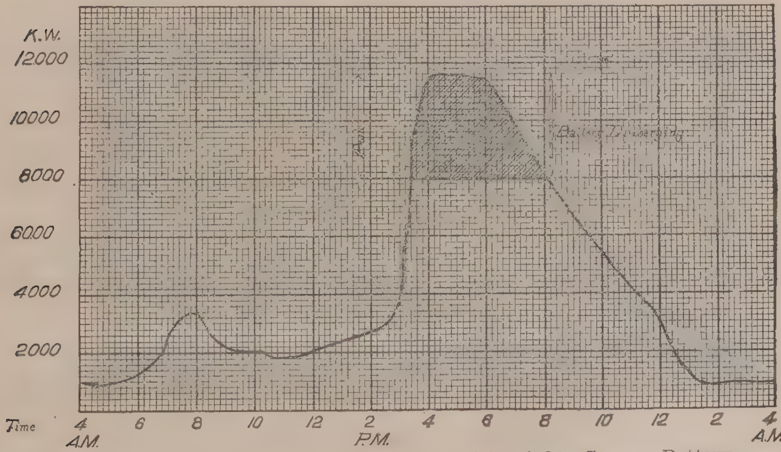


Fig. 20. Load Curve Showing "Peak" of Load Carried by Storage Battery.

Storage Batteries to Aid in Carrying the Maximum Load. Assume, in the case of the load diagram shown in Fig. 20, that the generating machinery is capable of supplying 8,000 kilowatts, and that a storage battery is used to furnish the remaining 3,600 kilowatts at the time of maximum load—that is, the *peak* of the load diagram. This simply means that batteries are substituted for a certain portion of the machinery plant, and the question is whether or not the substitution is of any advantage.

The first cost of a battery for a given rate of output depends simply upon the time of discharge. Batteries usually have a normal period of discharge of about 8 hours, at which rate the price of accumulators to furnish a given number of watts would be 3 to 5 times as great as that of the equivalent boilers, engines, and dynamos combined; but if the time of discharge is reduced to about 2 or 3 hours, the costs are about equal; and with a still higher rate, the cost of batteries would be less.

As a matter of fact, the storage battery secures other advantages, so that the total gain may be very important. For example, there is a reserve supply in case of accident; and the load may be made more uniform, as will now be explained.

Storage Batteries to Maintain Uniform Loads on Engines. Steam engines are very inefficient at light loads, and this fact often causes serious losses, especially in electric-lighting plants. Judicious selection of the number and sizes of the engines enables them to be worked in most cases at a considerable fraction of their full capacity nearly all the time. Nevertheless the storage battery gives greater flexibility to the plant, and renders it easy to increase the economy of the engines by making their loads still more uniform and nearer to their full capacities while they are running. The engines can be made to have a uniform full load, the battery being charged when the external load is light, and the battery taking the peak of the load when it is heavy.

Storage Batteries Used as Transformers. If the cells of a battery are arranged in series while being charged, and in parallel for discharging, a high voltage will be required for charging, and a low voltage will be given out. The amounts of energy measured in watt-hours are the same, less the loss of about 25 per cent which always occurs in accumulators; the result is similar to that obtained by an alternating-current transformer or motor-dynamo, but is less efficient. As an example, the equipment used at the Brooklyn Navy

Yard may be mentioned. It consists of about 250 small cells connected up in series parallel of 5 sets of 50 cells each and charged on a 110-volt circuit. When discharged, they are connected up all in series, and give about 500 volts, but with very small current. This equipment is used to furnish 500 volts for the *insulation test* of cables, and therefore requires little or no current.

Storage Batteries Used for Subdividing Voltage. The most important practical case is that in which a dynamo of 220 volts charges a battery of corresponding potential, a three-wire system being supplied from the battery, the neutral wire of which is connected to the middle point of the battery, as represented in Fig. 21.

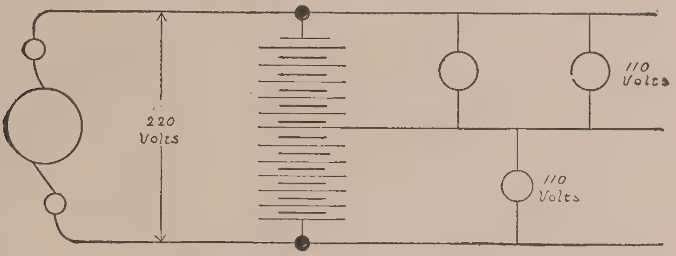


Fig. 21. Battery Used to Subdivide Voltage.

This arrangement avoids the necessity of running two dynamos, and allows the battery to be placed in a substation near the district to be supplied, so that it is necessary to run only two conductors to that point instead of three. The same principle may be applied to the five-wire system. When used in this manner, each side of the system requires its individual end cells and regulators.

The Hartford Electric Light Company was one of the first in this country to introduce the modern method of high-tension transmission, with low-tension 3-wire distribution.

The auxiliary battery used in connection with this equipment consists of 130 Chloride accumulators (65 on a side), each cell containing 31 negatives and 30 positive plates, each $15\frac{1}{2}$ by 31 inches, placed in lead-lined tanks measuring $58\frac{1}{4}$ by $21\frac{1}{2}$ by $43\frac{7}{8}$ inches. Fig. 22 is a diagram showing the general plan of the system. The power is transmitted 10.8 miles from the Farmington River Power Station to the Pearl Street Station, in Hartford, by means of step-up transformers, a 10,000-volt transmission line, and step-down transformers for distribution. From Pearl Street Station to State

Street, a distance of 3,000 feet, the current is transmitted at 2,400 volts, at which latter point, by means of step-down transformers and rotary converter, the storage battery is charged and the current distributed over a low-tension three-wire system.

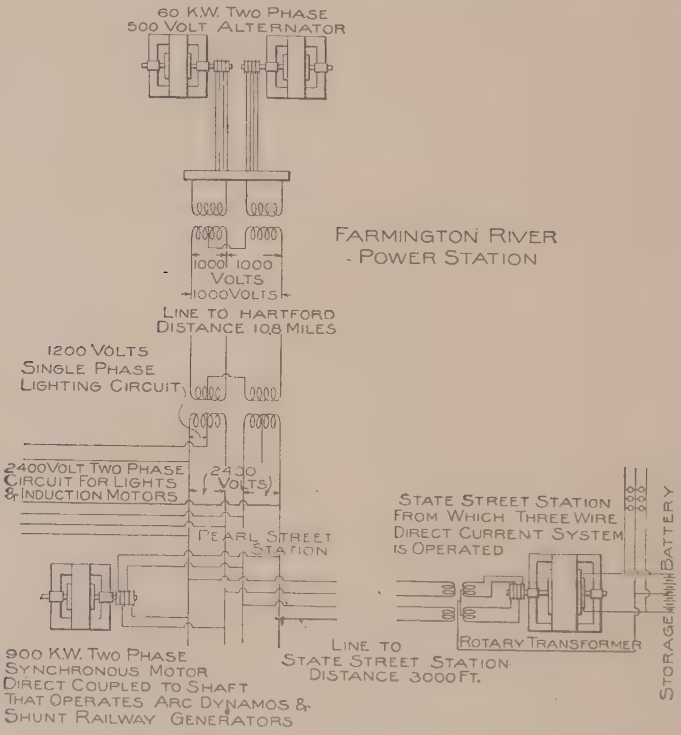


Fig. 22. Plan of Farmington River-Hartford Distribution System.

Storage Battery for Substations. The plan of installing battery plants at local centers, which are charged from the main station, enables some of the conductors to be saved in a three- or five-wire system, as already stated. It also makes it possible to reduce the size of these conductors, because the current which flows over them can be kept practically constant, so that it is not necessary to have them large enough to carry the maximum current consumed by the lamps, etc., which may be several times its average value. The generating machinery has the same steady load as if the battery were located near it.

The batteries at the various substations may be connected and charged in series or in parallel. The former plan would require far less copper in the conductors, since the voltage is multiplied by the number of batteries in series, and the current is the same as for a single battery. On the other hand, this great difference of potential would exist between the first and the last batteries of the series; and if either of these became grounded, any person connected to the earth and touching a wire supplied by the other battery would receive a shock due to the total voltage.

An excellent example of a storage battery substation is the Bowling Green Plant of the New York Edison Company. The Bowling Green Station furnishes an auxiliary supply of current directly from the battery, enabling the feeders, extended as tie-feeders into the Bowling Green building, to be used as distributing feeders to the system from both the Duane Street and Bowling Green Stations. While acting as an auxiliary supply to the general system, the battery also takes care of the distribution of current to the extensive installation in the Bowling Green building itself. The supply of current to charge the battery is taken from the Duane Street Station, about a mile distant, over four tie-feeders equipped with controllable disconnective switchboxes on the Bowker-Van Vleck system. This enables them to be used as tie-feeders by disconnecting them from the general system during the hours of light load, and as distributing feeders during the hours of maximum load, when they feed current into the system from each end. A considerable saving is thus effected in the investment, because costly feeders are not required to supply the maximum load to a distant part of the system.

This installation of an auxiliary source of current supply in the lower district makes it possible to shut down the generators in the Duane Street Station during the hours of minimum load, the supply of current to the district below 8th Street being derived from the battery plants at Bowling Green and 12th Street Stations, supplemented, if desired, by the supply of current from the 26th Street Station, over the tie-lines to 12th Street Station, whence the current is distributed through boosters raising it to the required potential, over the tie-feeders to the Duane Street Station switchboard. The battery and operating rooms of the Bowling Green

Station are located in the sub-basement of the Bowling Green Office Building. Vitrified hollow tile for conducting the feeder cables are laid under the battery-room floor, which consists of glazed white tile. Drains to carry off the water or acid run in the aisles between the cells, and lead to small cesspools which discharge into a lead drain-pipe.

The battery consists of 150 Chloride cells, 75 in series on each side of the three-wire system. The cells consist of wooden tanks, $40\frac{3}{4}$ by $21\frac{1}{2}$ by $30\frac{1}{2}$ inches, treated with an acid-proof paint and lead-lined, each containing 14 positive and 15 negative plates $15\frac{1}{2}$ inches wide by 31 inches high. Each tank is supported on four petticoat porcelain insulators resting upon 6-inch glazed tiles.

The plates are suspended in the tanks by shoulders resting upon sheets of heavy glass, which stand upon lead saddles in the bottoms of the tanks. The cells are connected by welding the plate terminals to lead bus-bars, no mechanical connections being used.

Twenty of the end cells on each side of the system are used for regulating, being separately connected to contact points on the regulating switches, which carry movable contacts operated by a screw. The potential is raised or lowered by cutting in or cutting out the regulating cells. Two regulating switches are connected in multiple on the positive, and two on the negative, side, to permit of discharging at two potentials, or to enable the battery to be charged and discharged simultaneously. The conductors between each series of cells, and between the regulating cells and the regulating switches, consist of copper bars 3 inches wide by $\frac{1}{2}$ inch thick. These bars are supported on porcelain insulators resting in hangers. The connections of this equipment are shown in Fig. 23.

The capacities of the battery at various rates of discharge are:

2,000 amperes per side for 1 hour.
1,000 amperes per side for 3 hours.
400 amperes per side for 8 hours.

Provision has been made in the battery-room, for the installation of a duplicate battery, which can be placed over the present plant. The booster is used to raise the voltage from that of the system to that required for charging the battery. The booster can be used also to raise the voltage of discharge for feeding some distant point of the system at a higher potential than would normally be required. The machine consists of one positive and one negative dynamo at each end of a common shaft driven by two motors. Each dynamo

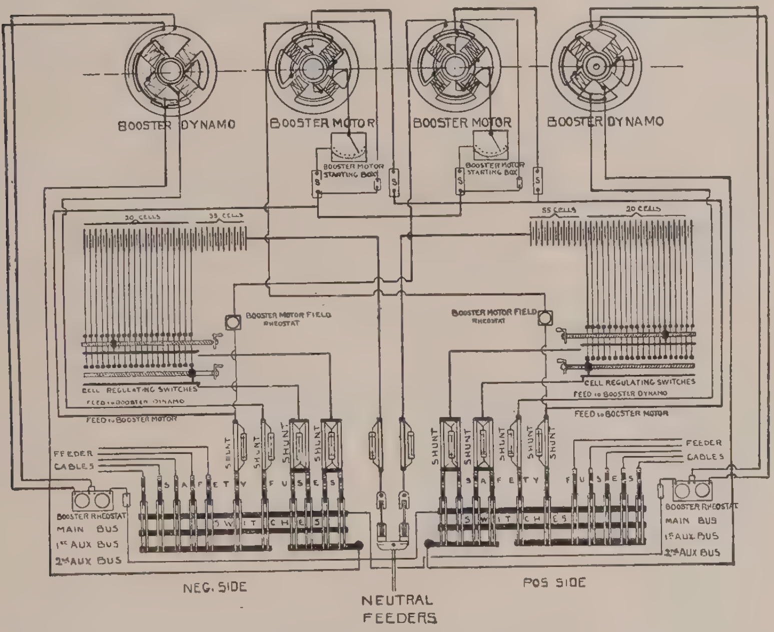


Fig. 23. Connections of the Bowling Green Storage Battery Substation.

has a capacity of 1,200 amperes, and a range of pressure up to 60 volts.

Storage Batteries Used for Two or More of the Above-Named Purposes. Each of the different uses has been considered separately to avoid confusion, but in most cases the storage battery is adopted in order to secure several advantages. By thus combining different applications, the plant is rendered not only more economical, but also more flexible. For example, the battery may be utilized to help out the generating machinery at times of heavy load, or when the latter is partially or wholly disabled. It often happens that it is difficult to produce or maintain sufficient steam pressure, owing to poor draft or other conditions, in which event a battery enables the boilers to be temporarily relieved of some or all of the drain upon them while the pressure is being raised to the proper point. It may also be necessary or desirable to shut down the machinery or a portion of it, temporarily, in order to make some repair or adjustment. It is also possible to feed some of the circuits from the battery while the others may be supplied at a higher or lower voltage by the machinery. In these and many other ways the storage battery may be a convenient adjunct to an electrical system. The fact that it is so radically different from the machinery in its nature and action, makes it very unlikely that the entire plant will be crippled at any one time, since the two sources of current are not exposed to the same dangers. An accident to the steam piping, for instance, might shut down all the machinery, but probably it would not affect the battery; and, *vice-versa,* an accident to the latter is not likely to extend to the former.

As an example of this application of the storage battery to several purposes, the following case may be cited:

The installation of storage batteries at the power house of the Woronoco Street Railway Company, in Westfield, Mass., presents features of special interest. After considering various methods of increasing the power-house capacity, rendered necessary by the construction of an extension of the line, it was decided that the storage battery offered the greatest advantages.

The station equipment consists of two 75-kilowatt multipolar generators belted to two 120-horse-power, high-speed, simple, non-condensing engines, steam being furnished by two 90-horse-power return tubular boilers.

The battery consists of 264 Chloride Accumulator cells, Type F–11, in glass jars of Type F–13, permitting an increase of 20 per cent by the addition of one pair of plates in each cell, and is installed in a small brick extension to the power house. The cells are located in one tier, each cell being supported on a sand tray resting on four glass insulators. The foundation for each row of cells consists of two stringers of wood suitably braced and supported on brick piers. This battery was not installed as a voltage regulator, the feeder system being so designed that the drop on the line is only a small amount.

By means of the battery, the load on the machinery is reduced within the capacity of one unit, leaving the second one as a reserve in case of an accident or an unusually heavy load. Without the battery, both machines would be needed nearly all the time.

The economy of operation due to using one unit instead of two, is clearly shown by the following station records:

	Date, 1899.	Lbs. coal.	Output kw.-hrs.	Lbs. coal. per kw.-hr.
With battery	Oct. 25–27	16,250	3,032	5.36
Without battery	Oct. 28	6,250	981	6.37

This shows an increase in the coal consumption, of 19 per cent, on the day when the operation of the battery was discontinued. The plant is also noteworthy from the fact that the station attendance is reduced to one man per shift, the engineer doing his own firing. This arrangement could not have been continued under the conditions of increased load, had it not been for the improved regulation and reduction of coal handling, and especially the increased reliability of operation secured by the battery.

On several occasions the battery has been called upon to carry the entire load of the system for an hour or so, during a temporary shut-down of the rest of the plant, as well as early in the morning or late at night, when only one or two cars are in operation.

Storage Batteries for Propelling Vehicles and Boats. The storage battery is usually about 35 per cent of the total weight in the modern electric automobile; and even with this great proportion, the distance run on one charge is seldom more than from 20 to 40 miles at a speed of about ten miles per hour, and that only on comparatively smooth roads. The ordinary battery equipment consists of about 44 cells of 108 ampere-hours capacity with an average discharge voltage of about 1.9.

In cities or where the roads are good, with charging stations close at hand, the electric automobile is superior to the gasoline types on account of the absence of explosive vapors, with the accompanying odor and noise. But for general touring they are not so handy, on account of the limited capacity of the battery.

The application of the storage battery to the street-car, while presenting such great advantages as the entire absence of poles and overhead wires, has not been a commercial success, mainly on account of the mechanical weakness of the plates, which are not able to stand the jolting and jarring or the rush of current due to frequent starts and stops. Another objectionable feature is the escape of acid fumes into the car, producing throat irritations and coughs among the passengers, although this is overcome by the use of fans.

The storage battery has been comparatively successful as a source of power in submarine boats, being charged while the vessel is on the surface, and discharged to run electric motors and lights when the vessel is manœuvering under the surface.

Storage Batteries in Telephone and Telegraph Systems. Since the adoption of the central battery systems by telephone companies, the use of the storage battery for this purpose has become very common, its advantages over the primary cell being as follows: Lower first cost; smaller space required (about $\frac{1}{4}$ of that occupied by an equivalent primary battery); greater constancy of E. M. F. and lower internal resistance; absence of the annoying *creeping salts;* and rapidity of recharge. The cost of storage-battery maintenance is about $\frac{1}{8}$ that of the primary cell.

In telephone work, the battery is installed in the district station, and charged when the line is not in use, from either a street connection or a generator in the station. When the line is in use for conversation, the charging current is automatically cut off, and the battery alone switched into service.

The storage battery in telephone work has become so important that the following description of a typical installation is given.

In the Filbert Street Exchange of the Philadelphia Bell Telephone Company, there are two generating units, forming a duplicate plant, each consisting of one engine, directly connected to a 30-kilowatt, 110-volt dynamo. These machines are run on alternate days, and are used for lighting the building and for furnishing power at 110 volts to various motor-generators. The latter comprise two 1.5-kilowatt machines for charging a 20-volt battery, one 1.5-kilowatt machine for charging an 8-volt battery; one 500-watt machine for charging a 4-volt battery; and two $\frac{1}{4}$-horse-power 75-volt alternating-current motor-dynamos for ringing call bells. Only one machine is installed for the 8-volt battery, and one for the 4-volt battery. Both batteries are in duplicate. To avoid a possible breakdown, a rheostat is furnished, so that the batteries of lower voltage can be charged from batteries or motor-generators of higher voltage. All machines are protected by automatic cut-outs.

The 20-volt battery consists of ten Chloride Accumulators having a capacity of about 1,000 ampere-hours, which furnish all the current needed by the subscribers for talking and for calling up the central office. The 8-volt batteries, in duplicate, consist of four cells, each having a capacity of 2,400 ampere-hours. This battery furnishes current for the "disconnect" signals on the operator's cords, and for the relays which cut out the subscriber's lamp signal when the operator answers his call, by plugging into the jack corresponding to the lamp signal.

Half the drop in potential of the 8-volt battery is in the 4-volt lamp, and the other half in the cut-out relay. This battery is in duplicate, so that one can be charged while the other is being discharged. This avoids danger of burning out the lamps, as the voltage of the battery is raised from 8 to 10 volts during charging.

Each of the duplicate 4-volt batteries comprises six 13-cells arranged in two sets. One of these sets consists of four cells, two in series, two in multiple; the other of two cells. The two extra cells are needed on one of the batteries to supply current for the operator's transmitters. The latter is arranged to furnish a current of four volts or two volts as desired. The 4-volt battery also furnishes all current for the lamp signals, which light when a subscriber takes his telephone off the hook. This lamp is put out when the operator answers the call. This battery also is made in duplicate, one being charged while the other is discharged, to avoid burning out the lamp from the higher voltage during charge.

Storage Batteries for Train Illumination. When cars are lighted by oil or gas lamps, these, owing to their size, and the heat produced by them, can be installed only in certain places, so that the distribution of light is not general, besides which, the heat and odor given off by the lamps are objectionable. The inflammable character of the illuminants involves great danger of explosion or fire in case of a train wreck. The absence of these disagreeable and dangerous features in electric lighting, is what has made its application so desirable in traction work.

Several methods of electric illumination have been tried on railroad trains. In one of the simplest of these, a small dynamo on the locomotive truck, or one perched above the boiler, is driven by a small steam turbine. While this is an economical method, it has the objection, that when the locomotive is uncoupled, the cars must be illuminated by some other means.

For this reason, the storage-battery system of supply has been adopted. One of the most successful methods is the "Axle Light" system. This, as its name implies, derives the motive power for its dynamo from the car axle. The mechanism is suspended from the bottom of the car, and is completely encased, so as to be dust-proof and waterproof. It comprises a small dynamo driven from a pulley on the axle of the car by means of a friction coupling.

The dynamo and driving mechanism are shown in Fig. 24. The former generates from 32 to 40 volts, depending upon the speed of the train, provided that it exceeds 15 miles per hour, the dynamo being then automatically connected to the battery and lamp circuit. An automatic device rectifies the direction of current, so that even though the direction of rotation is reversed, the battery is always charged in the proper direction. A variable resistance in series with the field coils is automatically adjusted by a small motor, so that even at high speed the normal limit of voltage is not exceeded.

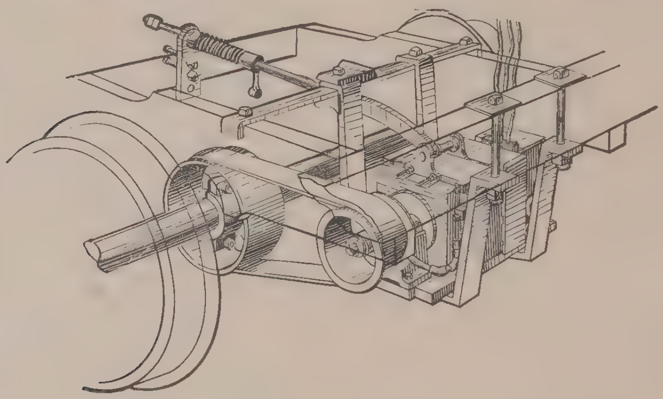


Fig. 24. Method of Suspension Used by the "Axle Light" System.

The lamps are 16-candle-power at 30 volts, the filaments being short and heavy so that they are not injured by vibration.

After the storage battery has been charged, it acts in parallel with the dynamo, and avoids fluctuations in voltage. When the car stops, the dynamo is automatically cut out, and the full supply of current is furnished by the battery, which is large enough for a ten-hour supply at full load.

Storage Batteries for Electrical Laboratories. The great advantage of this source of power in electrical laboratories, is the fact that any variation in the voltage is very gradual, and by the simple regulation of a rheostat in series with the battery, the operator can keep his voltage and current absolutely constant while a test or calibration is being made. When a large current is wanted, as in the case of ammeter calibration, the cells may be connected in parallel and discharged through a low resistance, thus cutting down the energy required for the test. A storage battery may also be used to step up the voltage, the cells being connected in parallel groups for charging, and in series for discharging.

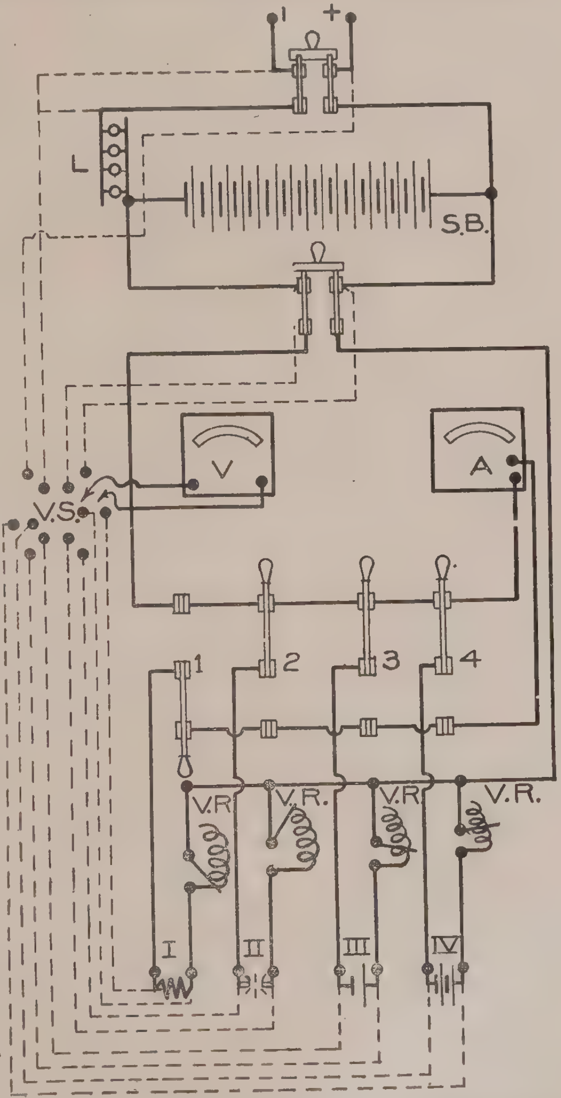


Fig. 25. Diagram of Connections of a Laboratory Equipment Arranged to Supply Current for Four Independent Operations.

The special arrangement shown in Fig. 25 consists of a storage battery *S.B.*, the charging current for which is regulated by a bank of incandescent lamps *L*. Where a large-capacity battery is employed, a rheostat or motor-dynamo can be substituted for the lamps. In the instance shown, four distinct operations may be carried on simultaneously, without having one interfere with the other. Each one of the circuits is supplied with a regulating device *V. R.*, so that any desired current density is obtainable at the electrodes of the experimental devices I, II, III, and IV. The arrangement of the voltmeter circuits is such that the voltage of each individual circuit can be readily obtained through the use of the twelve-point voltmeter switch at *V. S.* The switching arrangement is such that by means of one ammeter *A*, separate readings of the current in each branch circuit may be made, or the total current read. For example, with the switches as shown in the figure, the current flowing through the first apparatus consisting of a resistance furnace is being measured. If switch 1 were thrown in the opposite direction, and switch 2 had its position reversed, the current of group II would be shown by the ammeter. If all the switches were placed in the same position as

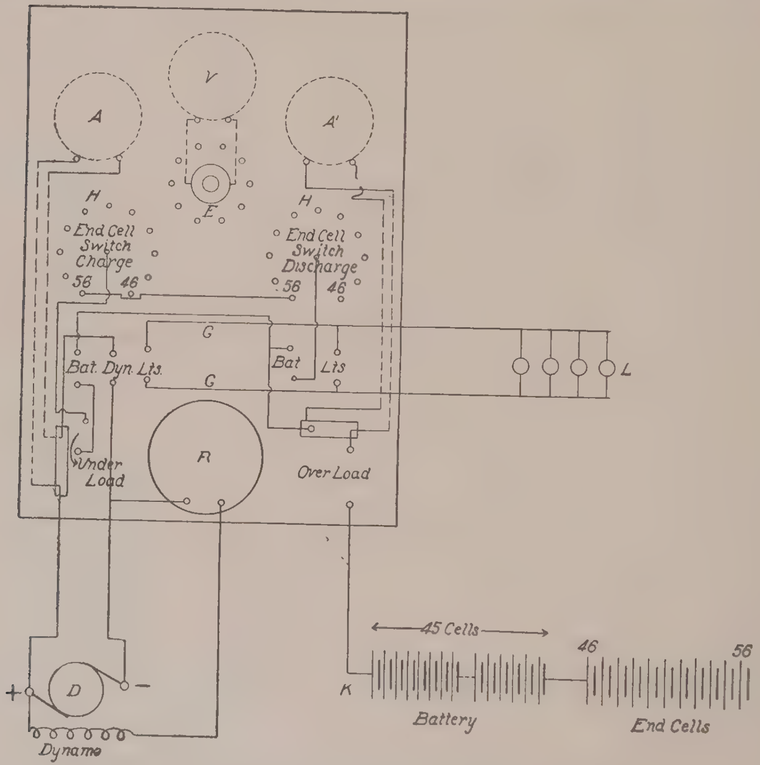


Fig. 26. Switchboard, Dynamo, and Battery Connections.

switch 1, the ammeter would indicate the total current drawn by the four pieces of experimental apparatus.

Connection and Regulation of Storage Batteries. The complete control of a battery in an electric-lighting plant requires provision to be made for feeding the lamps, etc., from either the dynamo or battery separately, or from the two working in parallel; and it should be possible to charge the battery at the same time that lamps are being supplied. To accomplish these results requires three switches—one to connect the battery to the dynamo, one to connect the lamps to the dynamo, and one to connect the lamps to the battery. In some plants the second switch is omitted, because the lamps are always fed by the battery alone, the latter being charged during the day, when no lamps are in use. However, it would seem desirable to have all three switches in every plant in order to be able at least

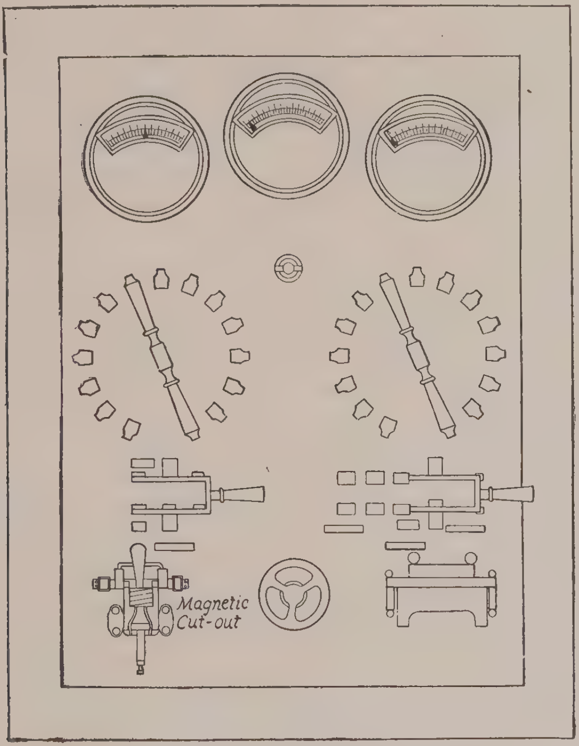


Fig. 27. Face of Switchboard.

to supply lamps and charge the battery at any time. In the battery circuit, there should be an ampere-meter having a scale on both sides of zero, so that it shows whether the battery is being charged or discharged, as well as the value of the current. Another similar ampere-meter is required in the circuit between the dynamo and the battery, to show the direction and amount of current. A third ampere-meter is desirable in the lamp circuit, to show the total current supplied to the lamps; but it need indicate only on one side of zero, since the current there always flows in the same direction. A voltmeter is required with a three-way switch, which enables it to be connected to the dynamo, battery, or lamps respectively.

An automatic overload switch must be inserted in the battery circuit so as to open or introduce resistance into the circuit when the current becomes excessive. An automatic cut-out is required between the dynamo and the battery to open the circuit when the charging current falls below a certain value, and thus avoid any danger of the battery discharging through the dynamo, if from any cause the E. M. F. of the latter drops below that of the former. This completes the ordinary measuring and circuit-controlling apparatus employed in connection with storage batteries. The arrangement is shown diagrammatically in Fig. 26, in which *A* and A^1 are the two ampere-meters, the third one being omitted in this case; *V* is the voltmeter; *E* the voltmeter switch to connect to the dynamo, battery, or lamps as desired; *G* the bus-bars; *L*, lamps; *D*, dynamo; *R*, rheostat in field-circuit of dynamo.

The regulating device consists of eleven end-cells, which are connected to corresponding contacts on the end-cell switches (Fig. 26). But as the drawing of these connections would complicate the figure, they have been omitted. Fig. 27 shows the switchboard with these devices mounted upon it.

Parallel Charge, Series Discharge. With batteries of small capacity, where it is not advisable or convenient to raise the generator voltage in order to charge all the cells in a single series, it is usual to divide the battery into two parts and charge each half of the battery individually, through a resistance from the main lines. This method is inefficient, however, and should be employed only with small equipments. Fig. 28 shows a diagram of connection for charging in this manner, and coupling the two halves of the battery in series during discharge, the discharge voltage being also regulated by resistance, there being no end cells employed.

Regulation of Storage Batteries. This is one of the most troublesome problems involved in the practical use of storage batteries. It arises from the fact that the voltage falls continually from the beginning to the end of discharge. To be sure, this decline is gradual; but its total value is large, being from about 2.2 to about 1.8 volts, which is a decrease of nearly 18 per cent.

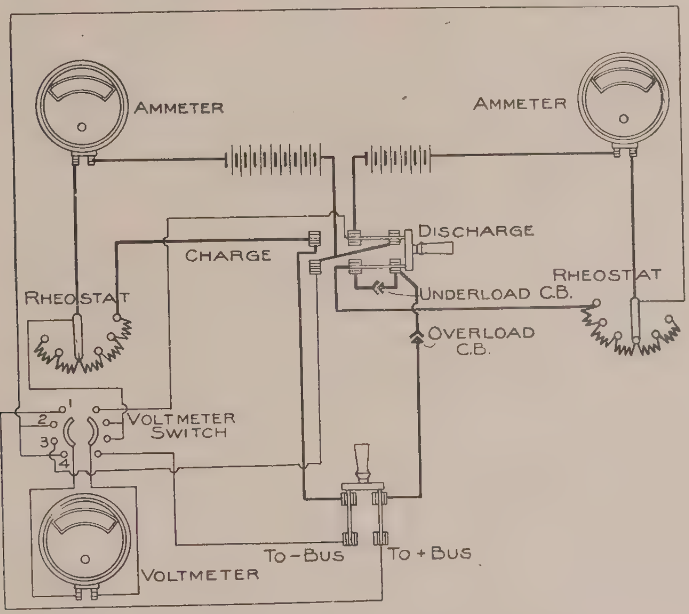


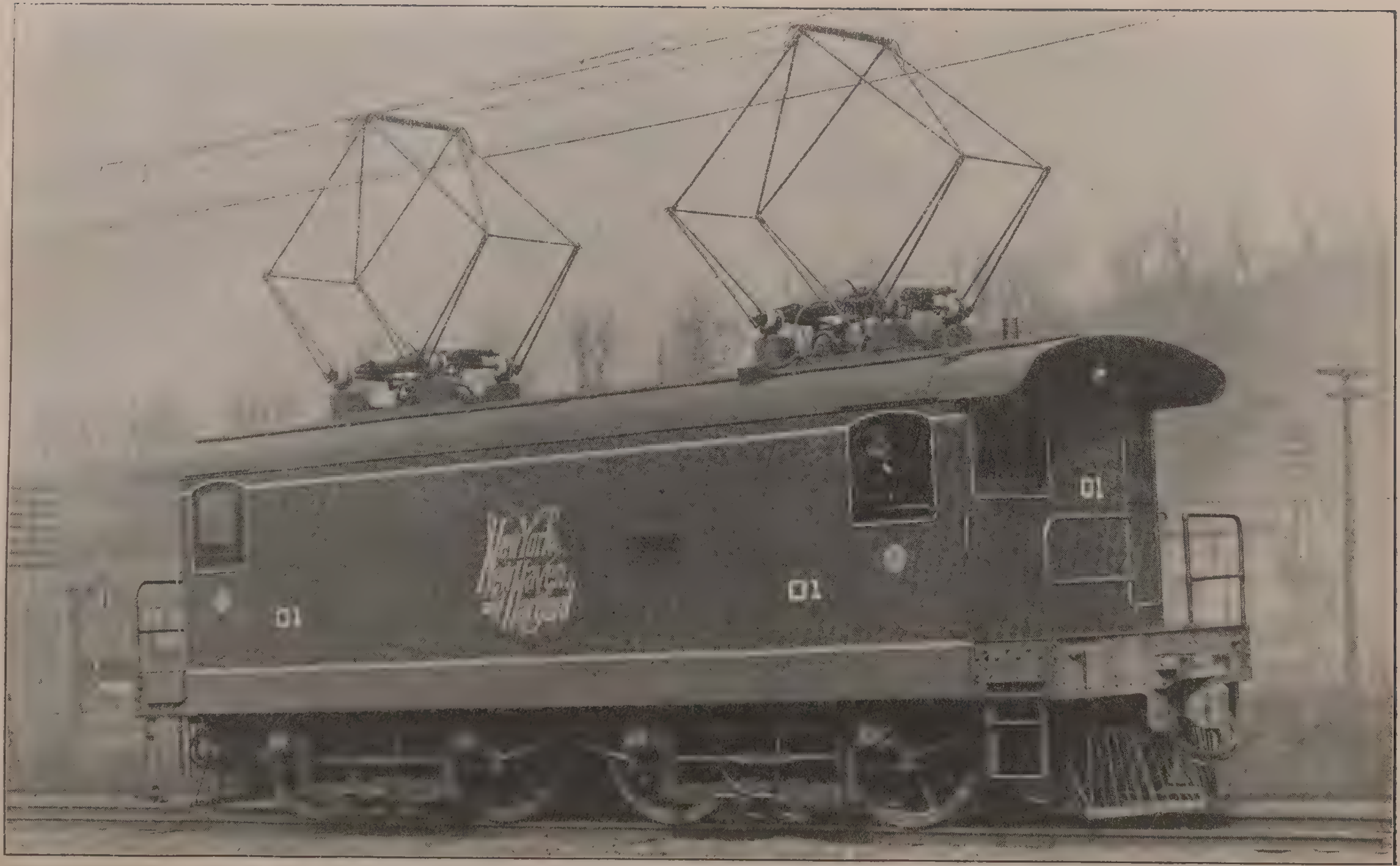
Fig. 28. Connections for Parallel Charge, Series Discharge.

In order to maintain a constant voltage, the usual plan is to have a number of extra cells, which are successively switched into circuit as the potential falls. These reserve cells and the switches which control them are represented in Fig. 26.

The contact-pieces of these switches must be made in such a way that they do not short-circuit the cells as they pass from one point to the next. This is accomplished by splitting the movable contact arm into two parts, between which a certain amount of resistance is introduced, so that when the two parts happen to rest on two adjacent contact-points, the resistance prevents the cell which is connected to these two points from being short-circuited, and also avoids breaking the circuit.

The number of extra cells depends upon conditions; for 110-volt lamps, it would require 51 cells to obtain 112.2 volts when fully charged and giving 2.2 volts each, assuming the drop on the conductors at 2 per cent. When the battery becomes discharged, and its potential falls to 1.8 volts per element, 10 additional cells, or 61 in all, would be needed. These would yield 111.8 volts, assuming the average potential of the reserve cells to be 2 volts, since they have not been discharged to the same extent as the original battery. If the drop on the conductors is 10 per cent of the lamp voltage, the potential at the battery will have to be 110 + 11 = 121. This will necessitate 4 more elements, or a total of 65, when the 51 original cells are fully discharged to 1.8 volts, and the 14 extra cells give 2 volts each.

For a three-wire system, the above figures should, of course, be doubled. This switching of extra cells into and out of the circuit obviously results in discharging them unequally; hence they require to be charged to a corresponding extent. This is accomplished by successively cutting the cells out of circuit as soon as they become fully charged, the last cell which was put into the circuit being fully charged in the shortest time, and so on. The amount of charge is determined by the methods already given. If the cells employed are not injured by overcharging, they may be left in circuit until the entire battery is fully charged. This saves the trouble of operating the switch; but it is wasteful of energy, since the full counter-E. M. F. and resistance of the charged cells must be overcome, which requires about 2.5 volts more per element. The switches might be operated automatically by a voltage regulator or by clockwork.



ONE OF THE SINGLE-PHASE LOCOMOTIVES ON THE NEW YORK, NEW HAVEN & HARTFORD RAILROAD CO.
Note the two pantograph bow trolleys for collecting the current.

THE SINGLE-PHASE ELECTRIC RAILWAY.

In no other line of electrical activity have developments during the last few years been so rapid as in that of electric railway work, and from all indications the limit has not yet been reached.

Until recent years all electric traction has been dependent upon direct current as a motive power. This is due principally to the fact that the series direct-current motor is admirably adapted for such work, and no alternating-current motor had been developed which could be substituted for it. One of the great advantages possessed by the direct-current series motor is its large starting torque, which may be several times greater than that required to propel a car at full speed. This type of motor is also essentially a variable speed machine, and lends itself very well to wide variations in speed control; consequently, for many years, in this country at least, all advance was made along direct-current lines.

The trolley voltage used at first was from 450 to 500 volts, this being supplied directly to the cars by means of a trolley wire, the rails being used for the return circuit. It is evident from the outset that the comparatively low voltage, necessitating as it did a correspondingly large current for a given amount of power, would place a definite limitation on the use of such a system for anything other than purely local distribution. To overcome this difficulty as far as possible, the trolley voltage was gradually raised to 600 or 650. This of course decreased the required current, thus increasing the scope of the system accordingly. The limit of increase of direct-current voltage on the trolley was reached at about this point, and the fact was recognized that some means must be devised for using a still higher voltage, since there are difficulties to increasing the trolley voltage beyond 600 or 700, due to flashing of the motors, which seems to increase directly with the voltage.

It may be mentioned in passing that one prominent electric traction expert has stated that a direct-current trolley voltage of 1500 can be used, but it remains to be proven whether or not he is correct.

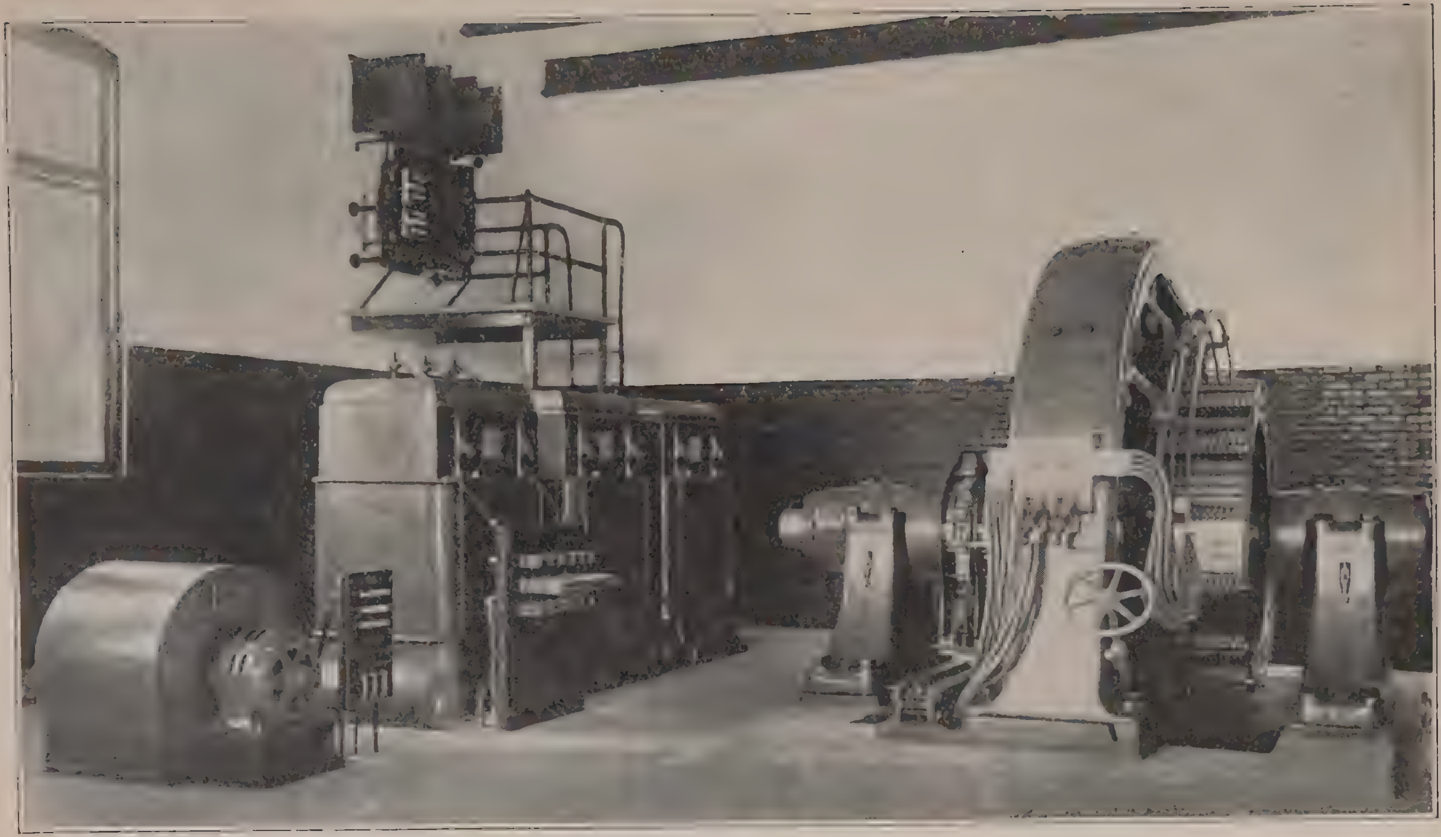
A very satisfactory solution of the problem for large city street railway systems and long interurban roads, consists in the use of a combination alternating-current direct-current system in which three-phase high tension alternating current is generated and distributed on high tension lines to substations along the road. It is here stepped down by means of transformers, and then changed to direct current by rotary converters, and supplied to the trolley wire as direct current at the usual voltage of say 600. This system has many advantages, as there is but small loss in the high-tension lines, and these lines can be made comparatively small, thus effecting a considerable saving in investment for copper.

The above mentioned system of distribution is very generally used, and has been found quite satisfactory. The substations can be located at frequent intervals, and the distance that the 600-volt current must be conducted to supply the cars is not great. By this means current can be distributed over wide areas with a small loss, where it would be impossible to use the straight direct-current system of distribution.

While, as stated, this furnishes a fairly satisfactory solution of the problem, it is far from perfect, as it necessitates the intervention of the rotary converter substation, in which the investment must be large; and moreover the cost of operation is high, as such a station requires skilled attendance on account of the somewhat intricate nature of the rotary converter. The ideal system, therefore, is one which does away altogether with the use of direct current, the power being generated, distributed, and utilized by the motors, as alternating current.

Three-phase induction motors have been used quite extensively and with considerable success in Europe for many years past. The three-phase motor, however, is not entirely adapted for railway work, since it possesses the characteristics of the shunt rather than of the series motor, being a constant speed, not a variable speed machine. Moreover, two trolley wires are necessary instead of one, and still another disadvantage consists in the low power-factor of the three-phase induction motor at starting.

The recent application of the single-phase alternating current to railway work has opened up a new field, which bids fair to supplant all other forms of distribution to a great extent at least, and

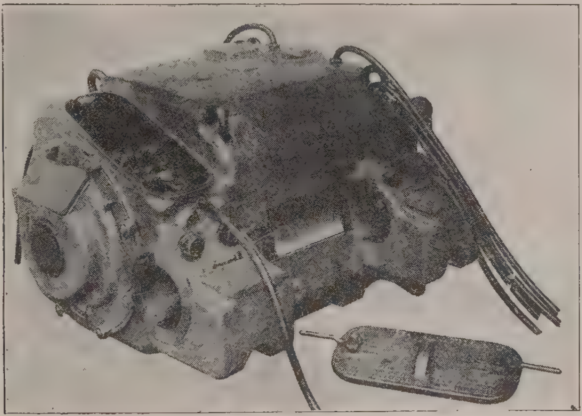


INTERIOR OF SUB-STATION SHOWING ROTARY CONVERTER AND TRANSFORMERS.

The three phase current is delivered to the transformers where it is stepped down to the voltage required for the rotary converter. In this machine it is transformed to direct current and delivered to the trolley wire.

it is impossible to predict at the present time just what its limitations may or may not prove to be. This has been made possible by the development of a *practical commercial* single-phase motor, which permits of the use of alternating current on the trolley wire with all its advantages, and yet sacrifices few, if any, of the advantages of the direct-current series motor on the car.

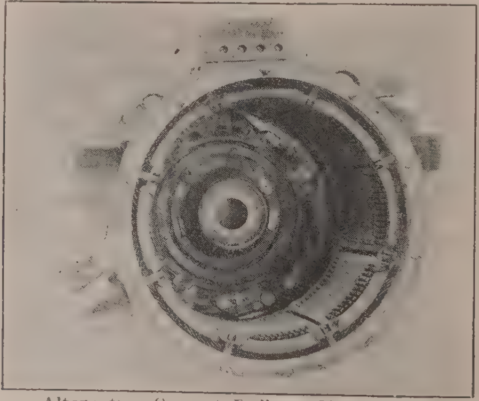
This motor, which is the latest and most important development in the electric railway field, is of the series commutator type, and does not differ in principle from its direct-current contemporary. It is called the *commutator type single-phase* motor, and is the one type of alternating-current motor which has the same desirable characteristics for railway work as the direct-current series motor.


Compensating Alternating-Current Railway Motor.

At first thought it may seem strange that a motor built fundamentally on the same lines as a direct-current machine would operate on an alternating current, as it might appear that the motor would tend to turn first in one direction and then in the opposite direction with no resultant motion. This, however, is not the case, because the direction of rotation of a motor depends upon the relative direction of its field and armature currents. If now the field were maintained in a constant direction and the armature supplied with alternating current, then the tendency would be to rotate first in one direction and then in the other, it is true, but as a matter of fact the alternating current is supplied to the field in series with the armature, so that when the direction of current in the armature changes it also reverses in the field. The result is that the relative direction of current in the field and armature is constant and the motor has, therefore, a tendency to turn continuously in one direction as long as the alternating-current power is supplied.

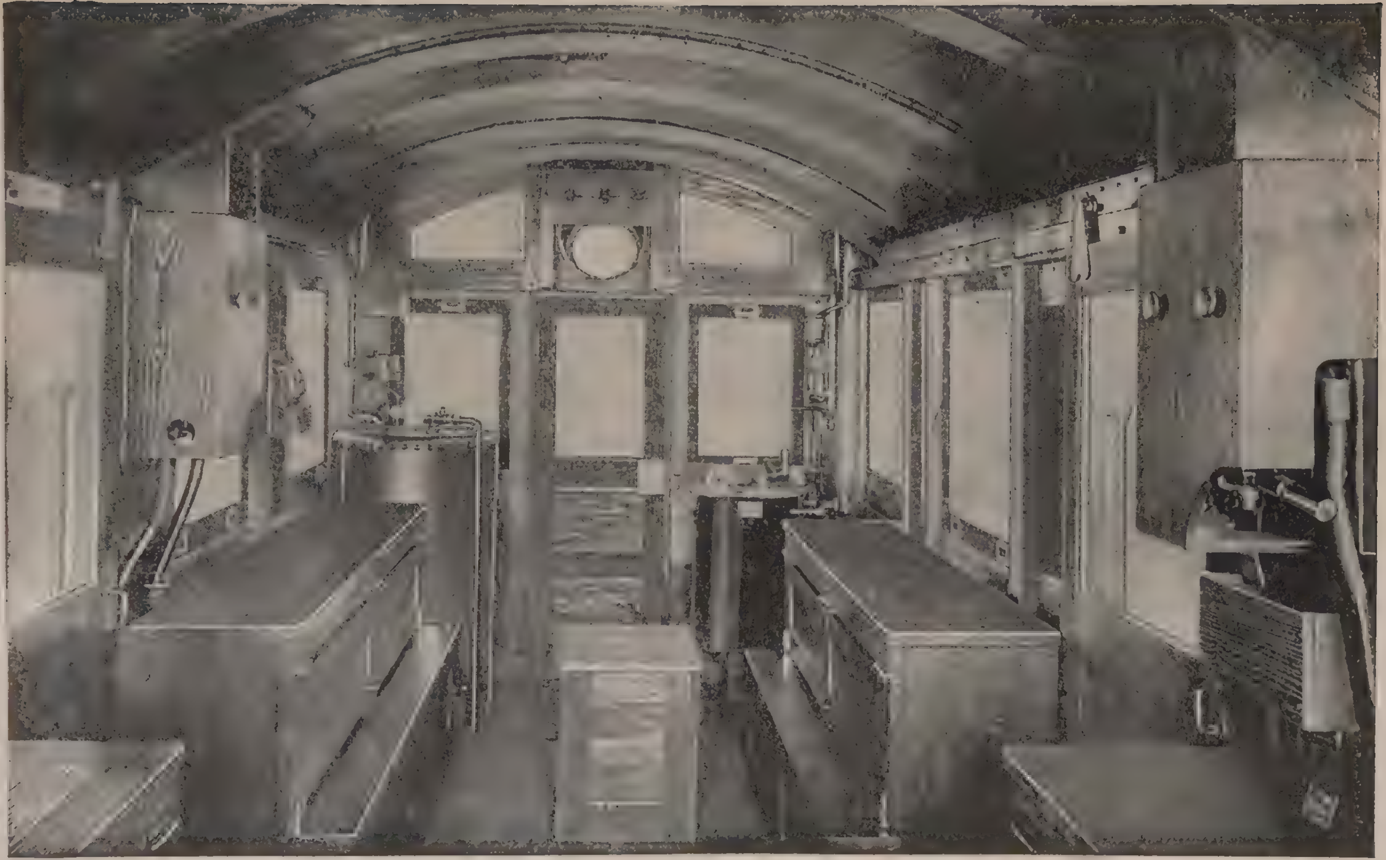
This being true, the question may arise as to why the single-phase motor was not brought to the front for railway work long ago. The answer is that there were certain inherent difficulties to be overcome, and the development of the single-phase motor has been simply the removal of these difficulties, rather than the design of an entirely new type of machine.

The most serious obstacle to overcome is the sparking at the commutator, due to the fact that when the terminals of a coil are bridged by a brush, the coil acts like the short circuited secondary of a transformer of which the field winding constitutes the primary. Also there is an iron loss due to the alternating magnetic flux through the magnetic circuit; while another objectionable feature is the counter E.M.F. induced in the field coils.



Alternating-Current Railway Motor Field.

In order that it may overcome these difficulties, to some extent, at least, the single-phase motor presents certain modifications from the direct-current type, in that it has more field poles, and the entire magnetic circuit of field frame, cores, and pole pieces, is carefully laminated. The number of commutator segments is also increased, thus reducing the number of armature turns per coil, and there are special features introduced to prevent sparking, such as compensating windings which neutralize the effect of armature dis-

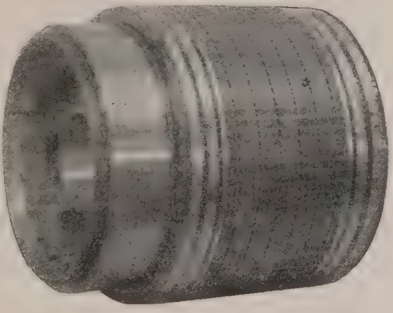


INTERIOR OF 160-TON B. AND O. ELECTRIC LOCOMOTIVE.

General Electric Company.

tortion; the use of narrow brushes; a type of armature winding which gives a low reactance per coil; the use of high resistance leads between the armature coils and commutator segments, etc.

The single-phase motor is then a refined and highly perfected type of direct-current motor, and this explains the fact that it will operate on either alternating- or direct-current circuits. In fact some claim that it will operate even more efficiently on direct current than the regulation direct-current motor itself.



Single-Phase Armature, Unmounted.

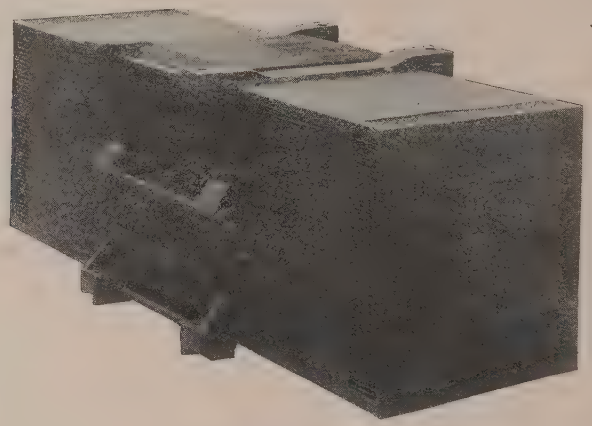
The field for which the single-phase motor seems particularly adapted is that of heavy service and interurban work, where it has many distinct advantages, among which may be mentioned the following:

The alternating current on the trolley allows the use of a high voltage and correspondingly smaller current, which reduces the line loss and permits of the use of smaller wire, which of course means a saving in the investment for copper. Moreover, the difficulty of collecting a large current from the trolley wire is overcome. Rotary converter substations are eliminated, being replaced by simple and cheap transformer substations, which require no attendance. The capacity can be easily increased by merely increasing the number of these transformer substations.

The efficiency of speed control is a point particularly worthy of mention. In direct-current speed control, the series-parallel method is used almost exclusively. This consists of putting the motors in series for low speed and in parallel for high speed. This permits of two, and only two, economical running points; the one at full speed, and the other at approximately half speed. All intermediate points must be obtained by the insertion of dead resistance in which the voltage is simply wasted as heat, thus causing a large loss particularly at starting.

With the single-phase motor the current is supplied to the car with a voltage of say 3300. It is then stepped down by means of transformers on the car to the voltage of the motors, which may be 200 or 250 volts. The speed is, of course, dependent upon the voltage applied to the motors, and this voltage is cut down from the maximum, to obtain various gradations, by means of an induction controller, or by taps from an auto-transformer. Thus the motor takes from the trolley only slightly more power than is actually required to operate it at any given speed, instead of taking full voltage from the line and absorbing part of it in dead resistance.

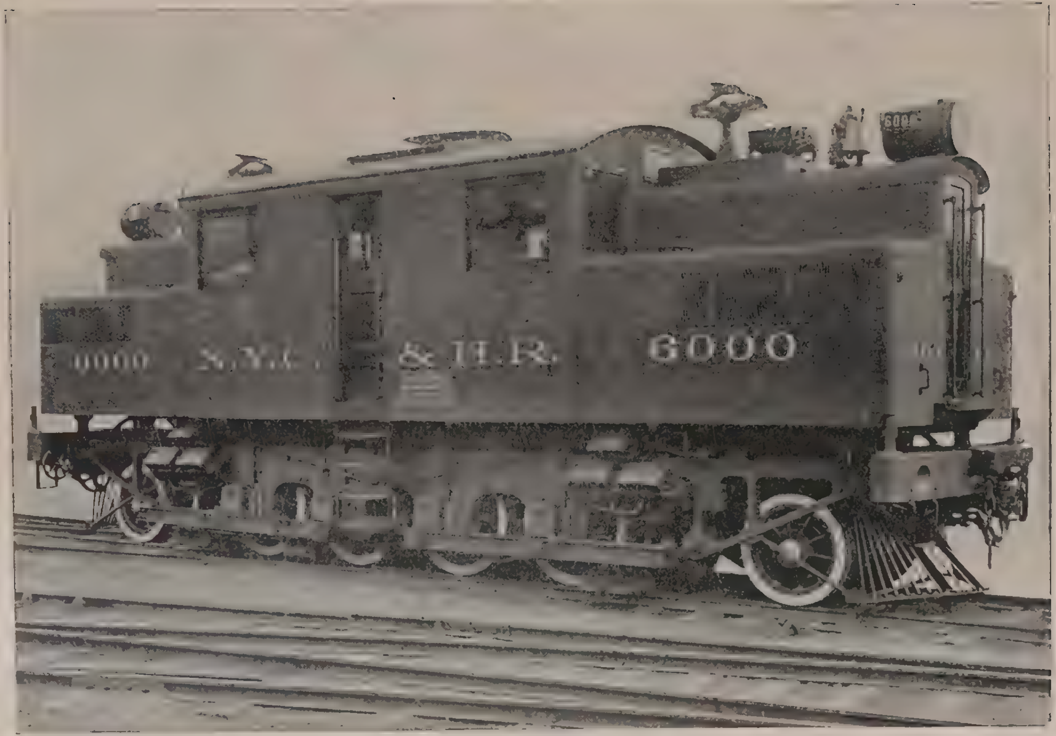
The effect of electrolysis upon neighboring water pipes paralleling an electric road, which is the cause of so much trouble with direct current, is entirely eliminated, as electrolysis evidently will not take place with alternating current.



Auto Transformer.

In connection with this system a sliding contact device or bow trolley has in many cases been substituted with considerable success for the ordinary current collecting device, or trolley wheel, one advantage of this being that the car can be run in either direction without reversing the contact device. Another very satisfactory form of trolley is of the pantograph type with sliding shoe, shown on the New York, New Haven and Hartford locomotive.

A new form of trolley suspension known as the catenary has been developed to meet the demand for more substantial construction necessitated by the high trolley voltage. This consists of a stranded galvanized steel messenger or supporting cable, from which the trolley wire is suspended at intervals of about 10 feet, thus keeping it at a uniform distance above the track.



95 TON ELECTRIC LOCOMOTIVE FOR NEW YORK CENTRAL RAILROAD.

General Electric Company.

The multiple-unit system of control can be used in connection with single-phase motors, this being the scheme which has been in use for a long time on elevated and other roads using direct current, whereby several cars can be operated in a train from a single point, each car being equipped with its individual motor and controlling apparatus. The entire system is then controlled as one unit by a single motorman stationed usually in the front of the first car. This method of control has become of such tremendous importance that any system to which it cannot be applied would be seriously handicapped. Cars equipped with single-phase motors can be operated on either direct-current or alternating-current lines, with high or low tension, with trolley or third rail.

It must not be supposed, however, that with all the above mentioned advantages, the single-phase system has no disadvantages, as such is not the case. The car equipment, due to the transformers and the nature of the motors, is considerably heavier. The motors themselves are more expensive on account of their special construction. The equipment is not always adapted for operation on existing lines. There is a slight increased "apparent" resistance of the trolley line and a considerable increased "apparent" resistance of the rails, due to reactance caused by the alternating nature of the current. There is also an active electro-motive force between the field coils, which is objectionable, and there is a possibility of interference with neighboring telephone lines. Furthermore, there is slight loss in power in the transformers on the car, while the power-factor of the motors is less than unity.

Master Controller Used in Connection with the Multiple-Unit System as Applied to Single-Phase Work.

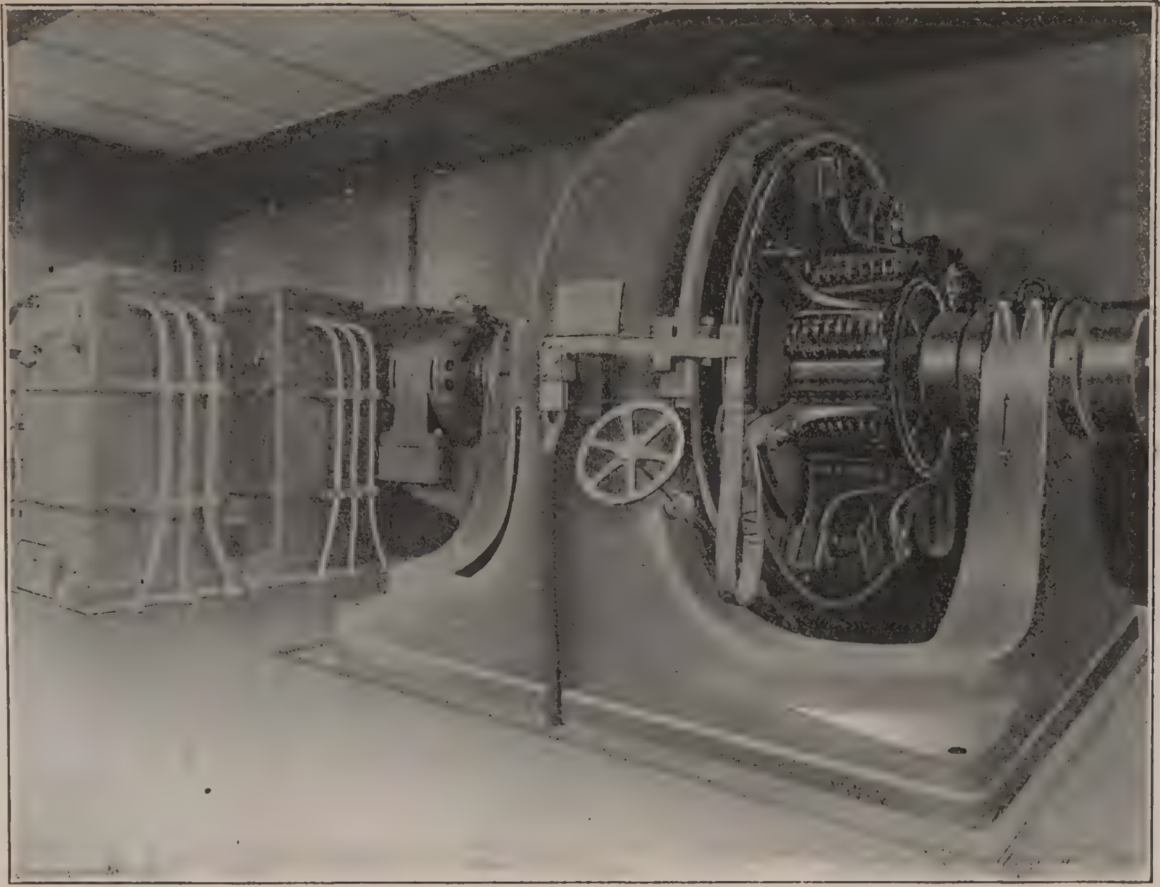
Summing the matter up as a whole, however, the advantages seem to overbalance the disadvantages, at least for many kinds of work, and it is safe to predict that this new system of operation will have a very wide and increasing application in the near future.

As to the operation of the system in general, the current may be developed by single-phase, two-phase, or three-phase generators, and supplied to the transformer substations just as it was formerly supplied to the rotary converter substations. Only a single phase is used on any section of the trolley line. The voltage on this transmission line will depend upon the existing conditions, and can be figured out like any other problem in power transmission.

Three-phase generators would ordinarily be used, as less copper is required to supply a given amount of power. The common frequency is 25 cycles per second. At the transformer stations, the voltage is then stepped down to that required on the trolley, which may be 2,000, 3,300, 6,600, or even 11,000 volts. While we cannot speak yet of a standard voltage, 3300 seems to be finding considerable favor. The voltage for which the motors are wound is 200 or 250, the General Electric motors using the former voltage, and the Westinghouse the latter. When operating on alternating current the motors are connected in parallel, and when running on direct current they are connected in series. Motors have been constructed from 50 to 225 horsepower, and there is no apparent reason why larger ones could not be made to operate with equal satisfaction.

Truck Complete with Single-Phase Motors and Contact Shoes.

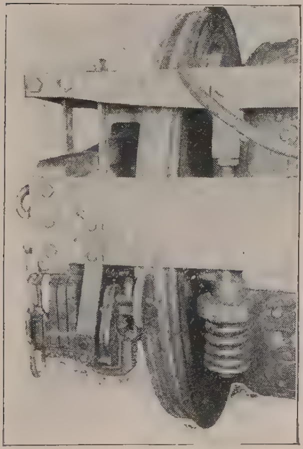
Among the roads in this country which are either using, or planning to use single-phase current, may be mentioned the Ballston-Schenectady line, which was one of the first systems to be equipped



800 K.W. THREE-PHASE ROTARY CONVERTER AND AIR BLAST TRANSFORMERS.

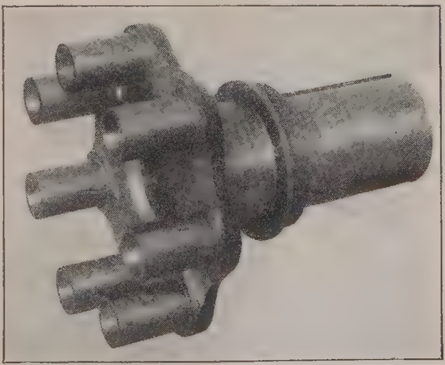
Manhattan Railway Company, New York City.

and has been in successful operation for some time. This road uses the alternating-current motor developed by the General Electric Co. The motors are adapted for operation on the 2,000-volt alternating-current trolley between cities, and on the standard 600-volt direct current in Schenectady. They are wound for 400 volts, and are operated in series on the 600-volt direct current. The frequency used is 25 cycles. Current is supplied by an overhead trolley, no feeders being used.


Magnetic Speed Indicator.

A second road of importance is one in Georgia between Atlanta and Marietta, which is 15 miles in length. This uses the Westinghouse equipment. The current on the trolley is 2,200 volts and 25 cycles. It is transmitted at a voltage of 22,000.

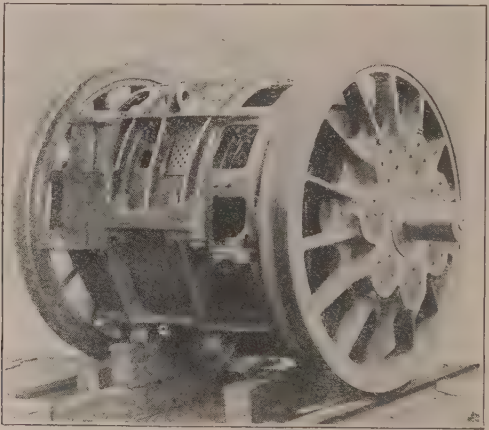
Another road of importance is the Indiana and Cincinnati interurban line, 41 miles in length, which has been in operation on regular schedule since July 1st, 1905. For 37 miles the road is operated from alternating current, and for 4 miles, from direct current. Four 75-horse power motors per car are used, capable of a maximum speed of 65 miles per hour.


Armature Quill.

The Bloomington, Pontiac and Joliet Electric Railway is a single-phase road equipped with General Electric apparatus, and has maintained a regular schedule over a distance of more than 10 miles since March, 1905.

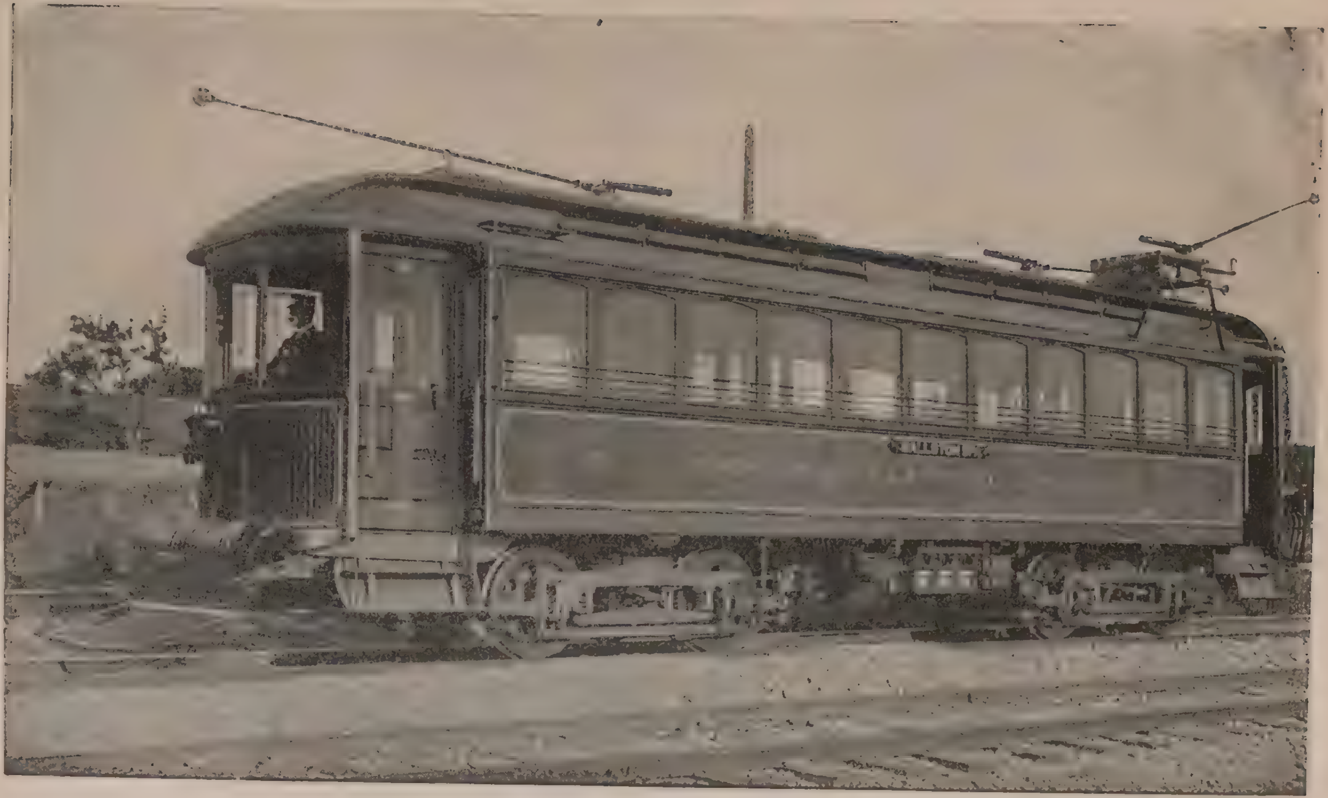
The plans are now being laid for a single-phase road, which will run south from Spokane, Washington, a distance of 150 miles. The current on the transmission line is 45,000 volts, which is stepped down to 6,600 on the trolley. The car will be capable of operating on current from a 6,600-volt alternating, a 700-volt alternating, or a 575-volt direct-current supply.

Perhaps the most important move which has been made in the direction of single-phase traction thus far is the decision of the New York, New Haven, and Hartford road to establish a long-distance passenger traffic on the single-phase system. According to the latest plans this road will operate between the Grand Central Depot and Woodlawn, N. Y., over the terminal tracks of the New York Central road, on direct current taken from the trolley. From Woodlawn, N. Y., to Stamford, Conn., the road will be operated on the single-phase system.



A Pair of Drivers with Single-Phase Motor Mounted upon Quill.

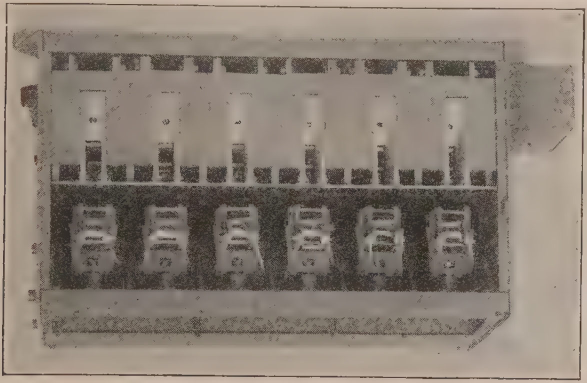
The equipment is being supplied by the Westinghouse Co. The current is generated by revolving-field type turbine-driven alternators. The armatures are designed for either three-phase or single-phase connection. The current is generated at 25 cycles and 11,000 volts, being delivered directly to the trolley, and thence to the cars, without the intervention of any transformers. The double catenary suspension from messenger wires is used to support the trolley. The locomotives are each equipped with four 200-H. P. gearless motors, designed to operate on 235-volt alternating current and 275- to 300-volt direct current.



ALTERNATING MOTOR CAR.

General Electric Company.

The armature is not mounted on the shaft direct, but is built upon a quill through which the axle passes with about $\frac{5}{8}$-inch clearance all around. There is a flange at each end of the quill from which seven pins project and fit into the hubs of the driving wheels. On the direct-current part of the line, current is delivered to the car through eight collecting shoes from a third rail. On the alternating-current section, current is delivered through two pantograph bow trolleys. On the direct-current section the series-parallel method of speed control is used, current being fed directly to the motors which are connected two in series permanently and the series-parallel control is applied to the motors in groups of two. The alternating-current speed control is accomplished by six taps from an auto-transformer for the corresponding running points. The cars weigh 78 tons and are capable of a speed of 60 to 65 miles per hour. The electro-pneumatic unit-switch type of control is used. At each end of the cab is a master controller from which the main controller is operated. Several locomotives can be operated together on the multiple-unit system, if desired.



Six-Unit Switch Group, Single-Phase System.

The Washington, Baltimore and Indiana single-phase road is the latest in the field, contracts having been placed very recently. The current will be transmitted at 33,000 volts and 25 cycles, then being stepped down to 6,600 volts on the trolley. The road will be 60 miles long and will be equipped with General Electric apparatus. Four 125-H. P. motors capable of operating on either alternating current or direct current will be used, and the cars will be capable of a speed of 60 miles per hour.

REVIEW QUESTIONS.

PRACTICAL TEST QUESTIONS.

In the foregoing sections of this Cyclopedia numerous illustrative examples are worked out in detail in order to show the application of the various methods and principles. Accompanying these are examples for practice which will aid the reader in fixing the principles in mind.

In the following pages are given a large number of test questions and problems which afford a valuable means of testing the reader's knowledge of the subjects treated. They will be found excellent practice for those preparing for Civil Service Examinations. In some cases numerical answers are given as a further aid in this work.

REVIEW QUESTIONS

ON THE SUBJECT OF

DYNAMO-ELECTRIC MACHINERY.

1. Explain briefly the two different methods of distributing electrical power.

2. (*a*) Why does the series characteristic curve bend over and the voltage begin to decrease when the current is large? (*b*) Explain why the E. M. F. of a series dynamo decreases very rapidly from about two-thirds its maximum value upon decreasing the current. (*c*) Draw a diagram of the circuit of a series dynamo.

3. (*a*) Why is the voltage of a shunt dynamo at its maximum an open circuit? (*b*) Why does the voltage of a shunt dynamo decrease when the load is increased? (*c*) Draw a diagram of the circuit of a shunt dynamo.

4. (*a*) What is the general form of the characteristic of a compound dynamo? (*b*) What is the difference between a long shunt compound-wound dynamo and a short shunt compound-wound dynamo? (*c*) Draw a diagram of the circuit of a short shunt compound machine.

5. What values of E. M. F. and current are used in plotting the external, internal and total characteristics of the shunt dynamo?

6. How does the construction of shunt coils differ from that of series coils?

7. (*a*) Why does sparking occur if the position of the brushes is such that the short-circuited coils generate no E. M. F.? (*b*) What is the correct position of the brushes for sparkless running?

8. Why should not the current pass through the springs which are used to give the brushes proper pressure upon the commutator?

9. Explain why armatures need to be very carefully balanced.

10. Give the advantages of carbon brushes, and state why they are especially useful for high potential machines.

11. Explain why the resistance of the field coils of a shunt dynamo is calculated so low as to require a resistance rheostat to be placed in series with it.

12. What are the general tests which should be made upon a dynamo?

13. (*a*) Name the best conductors of magnetism. (*b*) How does the reluctivity of air compare with that of copper, brass, wood, etc.?

14. Upon what does the value of the magnetic flux in a magnetic circuit depend?

15. How does the residual magnetism of a dynamo affect the characteristic curve?

16. (*a*) What features are important in the construction of a good commutator? (*b*) How should a commutator be cared for in order to secure good running?

17. Name the precautions that should be taken when installing dynamos.

18. Referring to the electric circuit we have the terms — electric flux, electromotive force and resistance. What are the corresponding terms for the magnetic circuit?

19. What are the causes of sparking at the commutator?

20. How does a ring-wound armature differ from a drum-wound armature?

21. (*a*) Explain the effect of the series coil of a compound dynamo. (*b*) Explain why both shunt and series coils are required to make a dynamo self-regulating. (*c*) What is the effect if the series coil does not have enough turns? (*d*) What is the effect if the series coil has too many turns?

22. State the special advantages of a toothed armature core.

23. (*a*) Name the magnetic density per square inch usually allowed for field magnets of cast iron. (*b*) Of wrought iron (*c*) Of cast steel.

24. (*a*) What are horse-power curves? (*b*) What are resistance lines?

REVIEW QUESTIONS

ON THE SUBJECT OF

DIRECT CURRENT MOTORS.

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1. State briefly the fundamental principle of a motor.

2. Upon what does the speed of a motor depend?

3. The armature resistance of a motor is .6 ohm and the E. M. F. applied at the brushes is 120 volts. When the counter E. M. F. is 82 volts, what current passes in the armature?

Ans. 63.+ amperes.

4. Explain why the speed of a series motor on a constant potential circuit increases when the load is removed.

5. What are the different ways of reversing the direction of rotation of motors?

6. If the output of a motor is 60 horse-power and the armature makes 490 revolutions per minute, what is the torque?

Ans. 643.+ foot-pounds.

7. Why is it necessary to cut out the starting resistance of a motor in order that it may be brought up to speed?

8. In what direction will the armature of a shunt generator rotate when run as a motor compared with the direction of rotation when run as a generator? Explain.

9. Explain briefly the different methods used to vary the speed of shunt motors.

10. A shunt motor on a 230 volt circuit takes 55 amperes at full load, the speed being 760 revolutions per minute. What resistance is it necessary to insert in the armature circuit in order to have the motor run at $\frac{2}{3}$ speed when the torque is $\frac{1}{2}$ that at full load? Ans. 2.8 ohms (approx.).

11. In stopping a shunt motor why should the main switch be opened *before* the armature circuit is broken?

12. What are the advantages and disadvantages of series motors?

13. The current in the armature of a shunt motor is 30 amperes and the E. M. F. at the brushes is 220 volts. If the armature resistance is .8 ohm, what is the counter E. M. F.? Ans. 196 volts.

14. What is the difference between the electrical and gross efficiency of a motor?

15. What is the commercial efficiency of a 500 volt motor which takes a current of 120 amperes, the output being 71.6 horse-power? Ans. 89 %.

16. Explain how a differential compound motor gives a constant speed.

17. Why is it unnecessary to use a starting resistance for series motors on constant current circuits?

18. The torque exerted by a 35 horse-power motor is 335 pound feet. What number of revolutions per minute does it make? Ans. 549 r. p. m. (approx.).

19. In the preceding example what is the pull in pounds at the circumference of the pulley if the pulley is 20 inches in diameter? Ans. 402 pounds.

20. What is the great objection to reversing a motor while running?

21. Shunt motors have what great advantage?

22. Explain how by overwinding the field coils of a series motor, nearly constant speed may be obtained with varying load.

23. How may the necessity of shifting the brushes of a motor with change of load be largely prevented?

24. In what cases may series motors be used to advantage?

25. (*a*) What is a cumulative compound motor? (*b*) State its advantages.

26. Why are motors but little used on constant current circuits?

27. The differential motor has what serious disadvantage?

28. The counter E. M. F. of a shunt motor on constant potential mains has what value when the output is a maximum?

29. A motor is to be installed that is to be frequently stopped and started under a heavy load, and must have a nearly constant speed. What kind of a motor should be used?

30. It is desired to run a compound generator as a motor and in the same direction as when run as a generator. (*a*) What connections if any must be changed? (*b*) Will it be necessary to move the brushes?

REVIEW QUESTIONS

ON THE SUBJECT OF

MANAGEMENT OF DYNAMO-ELECTRIC MACHINERY.

PART I.

1. Why is the steam turbine well adapted for direct connection?

2. On a three-wire system is it better to use 110-volt or 220-volt motors? Explain why.

3. Describe construction and operation of the Fort Wayne self-starting synchronous motor.

4. What methods are used for controlling the speed of induction motors? Which one is preferable?

5. How can the friction of brushes and bearings be tested roughly?

6. What points should be considered in the selection of a machine?

7. Give a sketch of the connections of a compound-wound motor.

8. What is the advantage of a synchronous motor when its field is over excited? Explain.

9. Give a safe rule to follow for personal protection when handling electrical circuits of a sufficiently high voltage to be dangerous.

10. What precautions must be taken in fixing a direct-connected set?

11. Why should starting boxes always be furnished with direct-current motors?

12. (a) How are small induction motors started? (b) Why cannot large sizes be started in the same way?

13. If a machine is to be taken apart for the purpose of cleaning or inspecting it, what precautions should be taken?

14. Describe the method of lacing a belt.

REVIEW QUESTIONS

ON THE SUBJECT OF

MANAGEMENT OF DYNAMO-ELECTRIC MACHINERY.

PART II.

1. In measuring resistance with the Wheatstone bridge, what is the objection of using a ratio of 1000 : 1 or 100 : 1?

2. Describe a tachometer. What advantage has this over the speed counter?

3. What is the torque of a 20 horse-power motor running at the rate of 600 r.p.m.?

4. When the armature of a machine becomes overheated and the belt is tight on the tension side, to what would you ascribe the cause and how would you remedy it?

5. Explain how to true up the commutator in case it becomes rough or uneven.

6. Describe a method of testing to see if the armature is centered between the pole pieces.

7. What is the pull in pounds in the case of a 40 horse-power motor if the speed is 550 r.p.m. and the pulley is 3 feet in diameter?

8. What do you understand to be meant by a ground in the armature?

9. If the speed of a generator is too high, what effect does this have on the voltage?

10. Describe with formula the direct-deflection method of measuring insulation resistance.

11. Describe a method of determining the current in a circuit if you have a voltmeter but no ammeter at hand.

12. How does eddy-current loss vary with the speed?

REVIEW QUESTIONS

ON THE SUBJECT OF

ELECTRIC WIRING

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1. Explain the three-wire system of wiring.

2. In case a test shows excessive leakage, or a ground or short circuit, how would you locate the trouble and remedy it?

3. Describe the construction and use of outlet-boxes.

4. What is the principal difference between alternating and direct-current circuits, so far as concerns the wiring system?

5. Compare the advantages of the two-wire and three-wire systems of wiring.

6. Under what general heads are approved methods of wiring classified?

7. A single-phase induction motor is to be supplied with 25 amperes at 220 volts; alternations 12,000 per minute; power factor .8. The transformer is 200 feet from the motor, the line consisting of No. 4 wire, 9 inches between centers of conductors. The transformer reduces in the ratio $\frac{2,500}{250}$, has a capacity of 30 amperes at 220 volts, and, when delivering this current and voltage, has a resistance-E. M. F. of 2.5 per cent, and a reactance E. M. F. of 5 per cent. Calculate the drop. (Use table and chart.)

8. What are the distinctive features of the different kinds of metal conduit?

9. Suppose power to be delivered, 300 K. W.; E. M. F. to be delivered, 2,200 volts; distance of transmission, 15,000 feet; size of wire, No. 00; distance between wires, 24 inches; power factor of load, .7; frequency, 100 cycles per second. Calculate line loss and drop in per cent of E. M. F. delivered. (Use table and chart.)

10. In installing A. C. circuits, what requirements are insisted on as to the placing of conductors in conduits?

11. Describe the manufacture, use, and special advantages of the different kinds of armored cable.

12. Describe three different methods of testing? Which is to be preferred?

13. What conditions determine whether a two-wire or three-wire system of wiring should be used?

14. In locating cut-out cabinets and distributing centers, what requirements should be fulfilled?

15. What is "knob and tube" wiring? Explain its use and discuss its advantages or disadvantages.

16. How far apart should insulators be placed?

17. What tests should be made before an electric wiring equipment is finally passed for acceptance? Give reasons.

18. What regulations govern the use of fibrous tubing?

19. What is meant by mutual induction?

20. What are the advantages and disadvantages of overhead linework as compared with underground linework?

21. Describe and illustrate by sketches proper methods of supporting and protecting conductors.

22. Discuss the advantages of running conductors exposed on insulators.

23. Illustrate by diagram, proper and improper methods of grouping conductors of two two-wire circuits.

24. What dangers are inherent in the use of moulding? What precautions should be taken to avoid them?

25. Describe the proper methods of laying out branch circuits, (*a*) in fireproof buildings; (*b*) in wooden frame buildings. Give sketches.

26. What methods of installing wiring are best adapted for the following classes of buildings, (*a*) fireproof structures; (*b*) mills, factories, etc.; (*c*) finished buildings; (*d*) wooden frame buildings?

27. What is skin effect? Its bearing on the problem of wiring?

28. In selecting runways for mains and feeders, what precautions should be taken?

REVIEW QUESTIONS

ON THE SUBJECT OF

ELECTRIC LIGHTING.

1. State the current, voltage, candle-power, and efficiency of the incandescent lamp most commonly used.

2. What do you understand by the "smashing point"?

3. Give the main points of difference between the three forms of arc lamp mechanism.

4. Mention the three principal parts of the Nernst lamp.

5. Describe with sketch the anti-parallel system of feeding.

6. Prove the law that illumination varies inversely with the square of the distance.

7. Why is arc light photometry a more difficult problem than incandescent?

8. Calculate the illumination three feet above the floor at the center of a room 18 feet square and 12 feet high, lighted by four 10-candle-power lamps 9 feet above the floor at the center of the side walls, assuming the coefficient of reflection to be 50%.

9. What material is used for the filament of incandescent lamps? Explain why.

10. From the curve given in Fig. 4, determine the efficiency which corresponds to the temperature of 1300° Centigrade.

11. What is the object of double carbons in an arc lamp?

12. What is meant by mean spherical candle-power?

13. What is the function of the heater in the Nernst lamp?

14. Describe the Bunsen Photometer.

15. How does the lighting of public halls differ from that of residences?

16. Why cannot platinum wire be used for the filament of incandescent lamps?

REVIEW QUESTIONS

ON THE SUBJECT OF

STORAGE BATTERIES.

1. What is the lowest voltage to which a lead battery should be discharged?
2. What means may be employed to make up for the drop in potential of storage batteries during discharge?
3. What causes sulphating?
4. What plate of a storage battery is the positive?
5. Describe the several indications by which the amount of charge in a storage battery can be determined.
6. How is the capacity of a storage battery usually expressed?
7. What is an electrolyte?
8. What is meant by a floating battery, and when is it applicable?
9. How must a storage battery room be arranged?
10. What causes buckling?
11. Why are there always more negative plates than positive plates in a storage battery?
12. Give several applications of storage batteries.
13. When a storage battery is charged, what is found on the positive plate? What is found on the negative plate? What occurs when the cell is discharged?
14. What is the maximum voltage obtainable from a lead storage cell?
15. How may sulphating and buckling be prevented?
16. How would you put a battery out of commission for a long period, and how would you place it in service again?
17. What is the difference in construction between Faure and Planté plates?
18. What is the essential difference between a primary and a storage battery?